ISSN 1635-3064

INSTITUT PAUL RICARD OCÉANOGRAPHIQUE

THE NEWSLETTER

DOSSIER

IS BIODIVERSITY *the solution?*

N°18 - 2020/2021

BIODIVERSITY

What if the solutions are right in front of our eyes?

The worldwide health crisis we are facing today has reminded us how closely our existence is linked to biodiversity.

The depletion of biodiversity, the scientists remind us, is one of the major factors that explain the emergence of increasingly prevalent viral diseases. Maintaining it is now more than ever a question of survival to combat the pandemics to come.

To tackle the viruses, constantly dormant in nature, and to prevent them from spreading, biodiversity has to be preserved. But that alone is not enough. For each species, it is imperative to conserve numerous populations and the broadest possible genetic diversity. That alone is capable of offering resistance to the viruses in circulation. They must encounter facing them a plethora of organisms capable of defending themselves, which also requires the protection of habitats.

In October 2020, the GIEC for biodiversity, IPBES (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services) published a report highlighting the importance of the preservation of habitats, both land-based and marine. It also stresses the necessity of a 'One Health' approach in national and international policy, an approach focused on the permanent interconnections between health and people, animals, plants and the environment.

We understand today the convergence between Ocean, Climate and Biodiversity, and it is through our understanding of this nexus that we shall find the solutions for adaptation and mitigation.

At a time when the exploration of Space is taking on a new impetus, we might now renew our exploration of Life, bring the Life Sciences and the Earth Sciences back to the core of our decisions. Our dream of Space has built a technology-based civilisation whose impact we can see today. It is urgent to bring biology back to the forefront of our priorities.

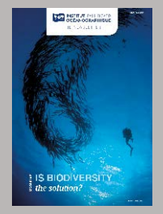
It is time to reset our awareness and to intensify our understanding of the living world and the interaction of ecosystems at planetary scale on which we are dependent, to understand that the protection of the Ocean, Climate, Biodiversity nexus should become the route map for all human activities, to intensify international agreements and commitments. And it is above all time to understand that nature-based and biomimetic solutions are the keys to our future.

We dreamt of walking on the Moon.
We might now dream of staying on Earth.

I shall leave the last word to Paul Eluard, who understood without seeing it that the planet is blue:
"Un autre monde existe, il est déjà dans celui-ci"
("There is another world, it is there already in this one").

This world is called Life.

Patricia Ricard
President of the *Institut océanographique Paul Ricard*



INSTITUT OCÉANOGRAPHIQUE PAUL RICARD
THE NEWSLETTER
N°18 - 2020/2021

Institut océanographique Paul Ricard
île des Embiez
83140 Six-Fours-les-Plages - France
Tel: +33 494 340 249
E-mail: embiez@institut-paul-ricard.org
www.institut-paul-ricard.org

Cover *- An image of the harmony between humans and nature: a diver face to face with a shoal of barracuda in the Red Sea (Ph. Adobe Stock/D. Brandelet).*

Editorial Director: Patricia Ricard - **Editor-in-Chief:** Christian Frasson-Botton - **Editors:** Claire Bertin, Isabelle Croizeau, Christian Frasson-Botton, Alain Riva, Nardo Vicente - **Editorial committee:** Patricia Ricard, Nardo Vicente, Christian Frasson-Botton, Alain Riva (consultant in biology), Claire Bertin, Isabelle Croizeau, Jean-Luc Bonnefont - **English translation:** Michael Paul - **Page design:** Ouvreboîte, Marseille - **Printer:** Groupe Taurrus Impression, Marseille. 100% recycled paper, label Imprim'vert 2009
Legal deposit: september 2021

INSTITUT PAUL RICARD OCÉANOGRAPHIQUE
www.institut-paul-ricard.org

Is biodiversity the solution?

Ph. DR

DOSSIER

WHAT GLOBAL FRAMEWORK TO PRESERVE BIODIVERSITY?

IN 2020, WHILE A VIRUS WAS SPREADING DEATH THROUGHOUT THE PLANET, BIODIVERSITY WAS THE CORE TOPIC IN THE MAJOR INTERNATIONAL CONFERENCES, ALBEIT OFTEN POSTPONED AND RESCHEDULED.

• **The World Conservation Congress of the International Union for the Conservation of Nature (IUCN),** initially planned for June 2020, then January 2021, will finally be held from 3 to 11 September 2021 in Marseille. The *Institut océanographique Paul Ricard* will be contributing, along with other research institutes.

• **The COP15 Convention on Biological Diversity** was to have been held at Kunming (China) in 2020. It will now take place from 11 to 24 October 2021. For the States, the aim is to establish a global biodiversity framework by 2030. The key measure is the preservation of at least 30% of the planet, with at least 10% under strict protection.

• **The future Treaty for the protection of biodiversity in the high seas was to have been presented at the United Nations General Assembly at the end of 2020.** *But according to some sources*[*]*, this agreement may well not make its appearance for at least another two years, after... 17 years of negotiations. There are high hopes, in particular for the creation of new conservation tools, especially marine protected areas.*

While these events are on the international agenda, the Sustainable Development Goals (SDGs) – adopted by the United Nations - remind us that biodiversity, the Ocean, the climate and water are intrinsically linked and enable the conservation of life on Earth.

Through the dossier in this Newsletter, the *Institut océanographique Paul Ricard* seeks to be associated with this dynamic with the publication of knowledge related to marine biodiversity. This is in phase with the enhancement of what the UN bodies refer to as 'Ocean literacy'. To this end, outreach to the general public has been a priority of this journal since it was first published in 1974.

Four eminent scientists offer their insights - well-documented, sometimes hitherto unpublished and based on passionate convictions. Their words reflect the personality and commitment of each of them in the face of a major challenge confronting our civilisation, the preservation of the living world.

(*) France Inter - '*Chroniques littorales*', by José-Manuel Lamarque, 12 May 2020.

Ph. Adobe Stock/olavs

Ph. A. Wimmer

INTERVIEW WITH

FRANÇOISE GAILL

Emeritus Director of Research CNRS
Vice-President, Ocean and Climate Platform

> *“Today, I think it’s time to link the climate issue to that of biodiversity with regard to what is an important ensemble: the Ocean”*

CAREER

1971
MSc, zoology.

1973
Joined a CNRS research laboratory.

1981
PhD, animal biology.
Muséum d’Histoire Naturelle, Sorbonne Université, Campus Pierre et Marie Curie, Paris.

1993
Developed a team specialising in the study of deep environments and adaptation to extreme environments.

2009
Set up the *Institut Ecologie et Environnement (INEE)*, CNRS.

Depuis 2013
Working at the United Nations on the assessment of the state of the oceans and sustainable development goals.

2014
Co-founder of the Ocean and Climate Platform, scientific coordinator, then Vice-President.

OCEAN - CLIMATE - BIODIVERSITY
THE NEXUS OF A LIVING PLANET*

1 /
THE OCEAN - CLIMATE - BIODIVERSITY NEXUS:
THE MAIN INTERACTIONS, THEIR IMPACT

2 /
UPGRADING SCIENCE AND KNOWLEDGE
ON THE OCEAN - CLIMATE - BIODIVERSITY NEXUS

3 /
SOLUTIONS TO MEET THE CLIMATE CHALLENGE AND PRESERVE BIODIVERSITY
WHICH ACTORS, WHAT ACTIONS?

The words followed by an asterisk (*) are defined in the Glossary.

The Ocean nexus

The living world at the heart of complex relations and interdependencies

Ph. Adobe Stock/Serp - Adobe Stock/Jarrod - Adobe Stock/artifirsov

Glossary

Nexus
From Latin, expresses the idea of links, interactions and connections between the different components of a complex whole. This is the case for the Ocean, the climate and biodiversity.

1/ The Ocean - climate - biodiversity nexus: the main interactions, their impact

➔ SINCE THE EARTH SUMMIT IN RIO IN 1992, THE MAJOR INTERNATIONAL CONFERENCES ON THE CLIMATE AND ON BIODIVERSITY HAVE BEEN WORKING SEPARATELY FROM EACH OTHER. AT COP21 IN 2015 IN PARIS, YOU KNOW FROM YOUR OWN EXPERIENCE HOW MUCH ENERGY AND WHAT ARGUMENTS IT TOOK TO INTEGRATE THE OCEAN IN CLIMATE ISSUES.
DO YOU THINK TODAY THAT THE OCEAN, THE CLIMATE AND BIODIVERSITY ARE COMPONENTS OF A SINGLE NEXUS?

Today, I think it's time to link the climate issue to that of biodiversity with regard to what is an important ensemble: the Ocean.

The Ocean is part of the climate system. It is the Ocean that in fact regulates climate change: because of its size in terms of volume, but also because of its relations with the atmosphere and with the continental interfaces. And the Ocean, it's also the largest part of the biosphere*. So as concerns the relation between the Ocean, the climate and biodiversity, it is certainly in the Ocean that the core of the processes that link these three elements are at issue.

On the Earth, we see a certain number of consequences concerning the erosion of the biodiversity, for example. But the relation with the climate will only be perceptible in the coming years through the Ocean ecosystem.

➔ CAN WE SAY THAT THERE HAS BEEN A BEFORE AND AN AFTER THE INDUSTRIAL REVOLUTION, WITH THE DISRUPTION OF A NATURAL EQUILIBRIUM?

Yes, because what is it that's a massive issue today and which is no longer doubted by anyone? It's the change in the carbon dioxide concentrations in the atmosphere, which is directly linked to the industrial revolution*.

When we look at the carbon dioxide concentrations in the atmosphere – known as the Keeling curve –, we can see that they have been rising inexorably year after year [1].

➔ WHAT ARE THE EFFECTS OF THIS CONSTANT INCREASE IN THE GREENHOUSE GASES IN THE ATMOSPHERE?

There are several. We can see straight away that if there's been a rise in the temperature of the Ocean – a consequence of the increase in concentrations of greenhouse gases * – there will be a change in the physical and chemical properties of the water [2]: a change that will alter a whole range of interactions between the ocean system and the atmosphere and the biosphere.

➔ IN PRACTICAL TERMS, HOW DO THE CHEMICAL ALTERATIONS IN THE OCEAN OPERATE AND WHAT IMPACT DO THEY HAVE?

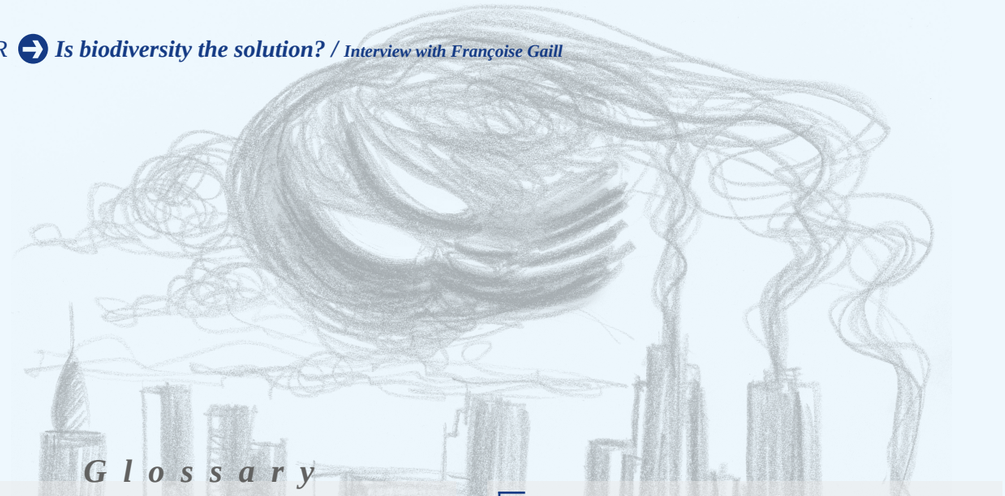
The absorption of atmospheric carbon dioxide that occurs at the surface of the Ocean through its contact with the atmosphere and because of the wind results in general in the dissolution to a greater or lesser degree of the carbon dioxide in the seawater. And this increase leads to a process of acidification* of the water [3].

>>

(1) To find out more: "We have really messed up the climate system and the Ocean" *– All about carbon… Interview with Laurent Bopp, Director of Research CNRS at the Laboratoire de Météorologie Dynamique (LMD), Institut Pierre-Simon Laplace, Paris. The Newsletter, Institut océanographique Paul Ricard, n° 17, 2019, p. 6.*

(2) To find out more: The Ocean, master of the climate - Interview with Dr Françoise Gaill, Emeritus Director of Research CNRS, Vice-President, Ocean and Climate Platform, The Newsletter, Institut océanographique Paul Ricard n° 14, 2015..

(3) The acidification of the seawater has increased by 30% in 250 years, since the beginning of industrial development, with a drop in pH from 8.2 to 8.1. This affects the calcification of marine organisms with calcareous skeletons (oysters, mussels, corals, plankton, etc.) and has an impact on the marine ecosystems and the services they provide.
To find out more: Acidification of the Ocean – Scientific factsheets on Ocean and Climate interactions, 2015, www.ocean-climate.org



Ph. Adobe Stock/carlacastagno

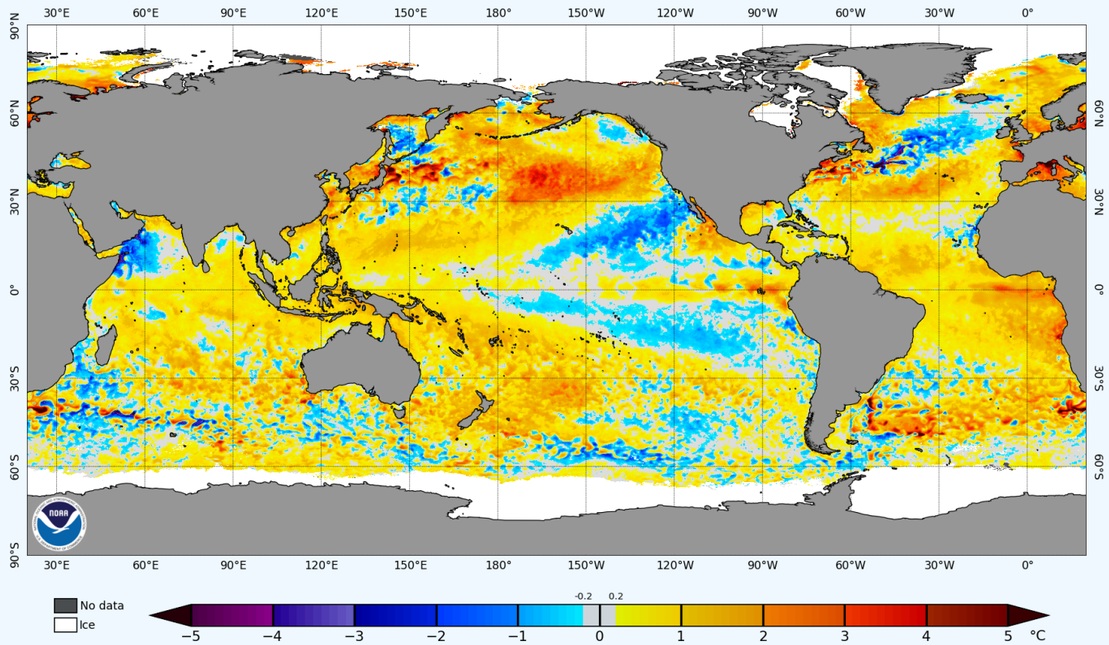
Glossary

Industrial revolution
Period of strong and rapid economic growth which began in Great Britain during the second half of the 18th century. It spread to Europe, then to other countries such as the United States of America. There was a second industrial revolution starting in 1896. This was the beginning of a strong increase in the use of fossil fuels: coal, petrol, etc.

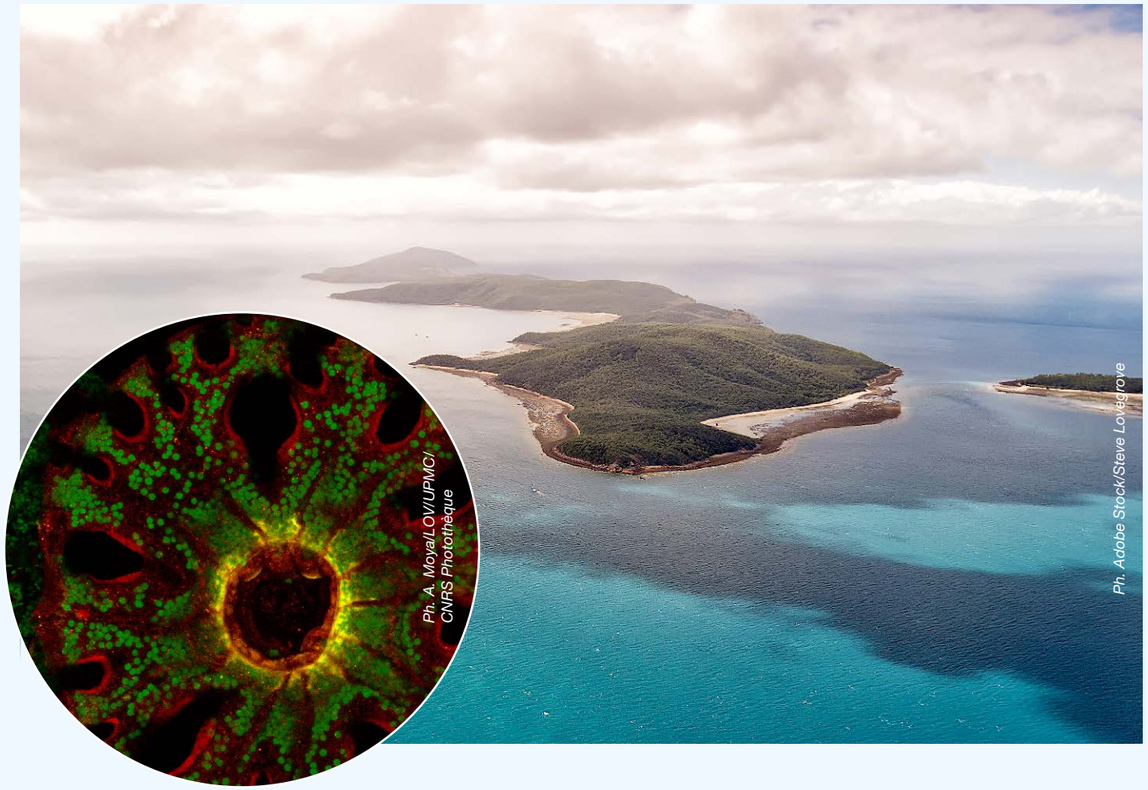
Greenhouse gases
Heated by the sun, our planet reflects back to the sky part of the energy in the form of heat-bearing infrared rays. The greenhouse gases, among them carbon dioxide, prevent part of these rays from reaching space. The increase of their concentration in the atmosphere is the cause of climate warming.

Biosphere
The living flora and fauna of the planet.

Acidification
Gradual decline in the pH in the seawater which is slightly basic (pH > 7). We speak of the acidification of the oceans when the pH becomes less basic.



Based on satellite data, the American National Oceanic and Atmospheric Administration (NOAA) produces maps of thermal anomalies, showing abnormal and above-average temperatures observed at the surface of the Ocean (de +5 °C à -5 °C). Here, the map from June 17, 2021. In white, ice-covered areas (Source: NOAA/NESDI 50 km Global Analysis: SST Anomalyl).



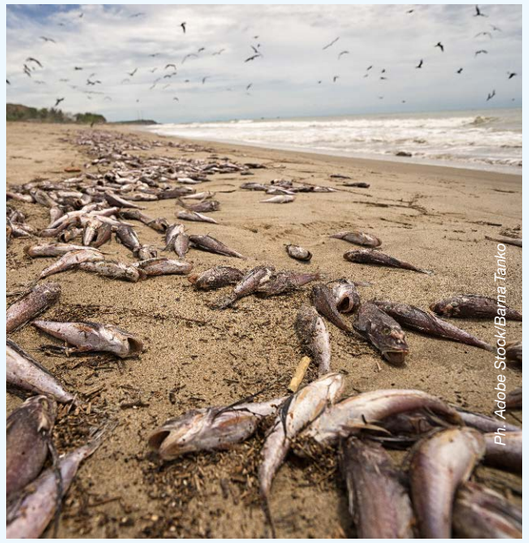
Polyp of Pocillopora damicornis *– a reef-constructing coral –, seen under a confocal microscope, enlarged 10-fold. It was sampled at Orpheus Island, on the Great Barrier Reef (east coast of Australia). This observation was carried out as part of the European project Epoca (CNRS). It is focused on the impact on the acidification of the oceans in relation with the growth of certain species of Cnidaria. The picture shows: in green, symbiotic* algae; in red, clumps of mitochondria* in the areas of calcification or growth of the skeleton.*

Glossary

Symbiotic (algae)
Unicellular microalgae that can live in symbiosis with marine animals (coral, anemones, jellyfish, nudibranchs, etc.). They provide various nutrients which are lacking to their host in tropical zones (source: https://www.encyclopedie-environnement.org/en/life/corals-ocean-engineers-under-threat/).

Mitochondria
Intracellular granules that play a very active role in all the phenomena of respiration and the energetic reactions in the life of a plant or animal cell.

Anoxia (or anoxic environment)
Designates the lack of oxygen in an environment. The depletion of the oxygen is so severe that it induces asphyxia in living organisms.



Hundreds of dead fish washed up on a beach at Zorritos, Peru (2018). The cause of this event has not been clearly identified. It may however be related to the phenomenon of anoxia that is very often encountered in the aquatic environment during episodes of extreme heat accompanied by strong atmospheric depressions, conditions favourable for the de-oxygenation of the water.

>>

➔ ARE THERE OTHER ASPECTS TO THE WARMING OF THE WATER?

In certain zones, the warming of the water has a major consequence: diminishing the concentrations of oxygen, inducing anoxia*. Over the past twenty years, we have observed an increase in these anoxic zones and in their surface area.

What happens in cases like that? All the species that pass through these areas die, because they need oxygen.

On the coasts of California, for example, there are times when the beaches are covered either with dead fish, or with oxygen-deficient shellfish, and these are really the consequences of a diminution of the concentration of oxygen in the seawater.

We can also observe that the increase in the water temperature [(4)] induces a stratification of the marine zones according to depth *[see opposite: A thermal stratification pattern that isolates]*. The thermohaline circulation resulting from the ocean dynamic occurs much more slowly, which also has a considerable impact on climate change *[see page 12: Powerful ocean currents which regulate the climate]*.

There are fairly complex relationships between the temperature, the carbon dioxide and the oxygen. And something we haven't talked about, because we still don't know much about the impact, is the integration of the salinity in these phenomena.

➔ WHY IS SALINITY IMPORTANT?

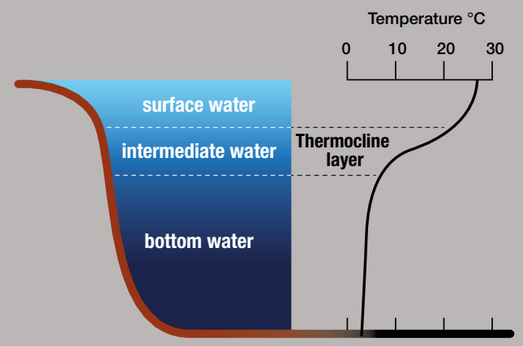
With the increase in temperature of the seawater and of the atmosphere, the melting of the ice is inevitable and will cause a difference in the distribution of the salinity of the water because of the difference in density

The non-salty water thus remains on the surface and is not drawn down towards the bottom in the same way. This phenomenon prevents the recycling of all the elements of the organic matter at depth, as used to happen before climate change.

>>

(4) The mean water temperature at the surface of the Ocean rose by 0.9% between 1901 and 2012, according to Prof. Callum Roberts of the Department of the Environment and Geography, York University, Toronto (Canada).

A THERMAL STRATIFICATION PATTERN THAT ISOLATES



The Ocean naturally presents a pattern of stratification linked to the temperature. The relatively warm water at the surface is separated from the cold water in the depths by a zone of rapid thermal variation called the thermocline.

The warming of the surface water increases the stratification, contributing to the intensification of the vertical temperature difference. This increases the isolation of the bottom water and thus reduces the exchanges, in particular of:

- nutrient salts indispensible for primary producers such as the chlorophyllian plants (diatoms, plants, marine algae, macrophytes*, phytoplankton, etc.) which transform mineral matter into organic matter;

- oxygen, making the deep water uninhabitable for certain species.

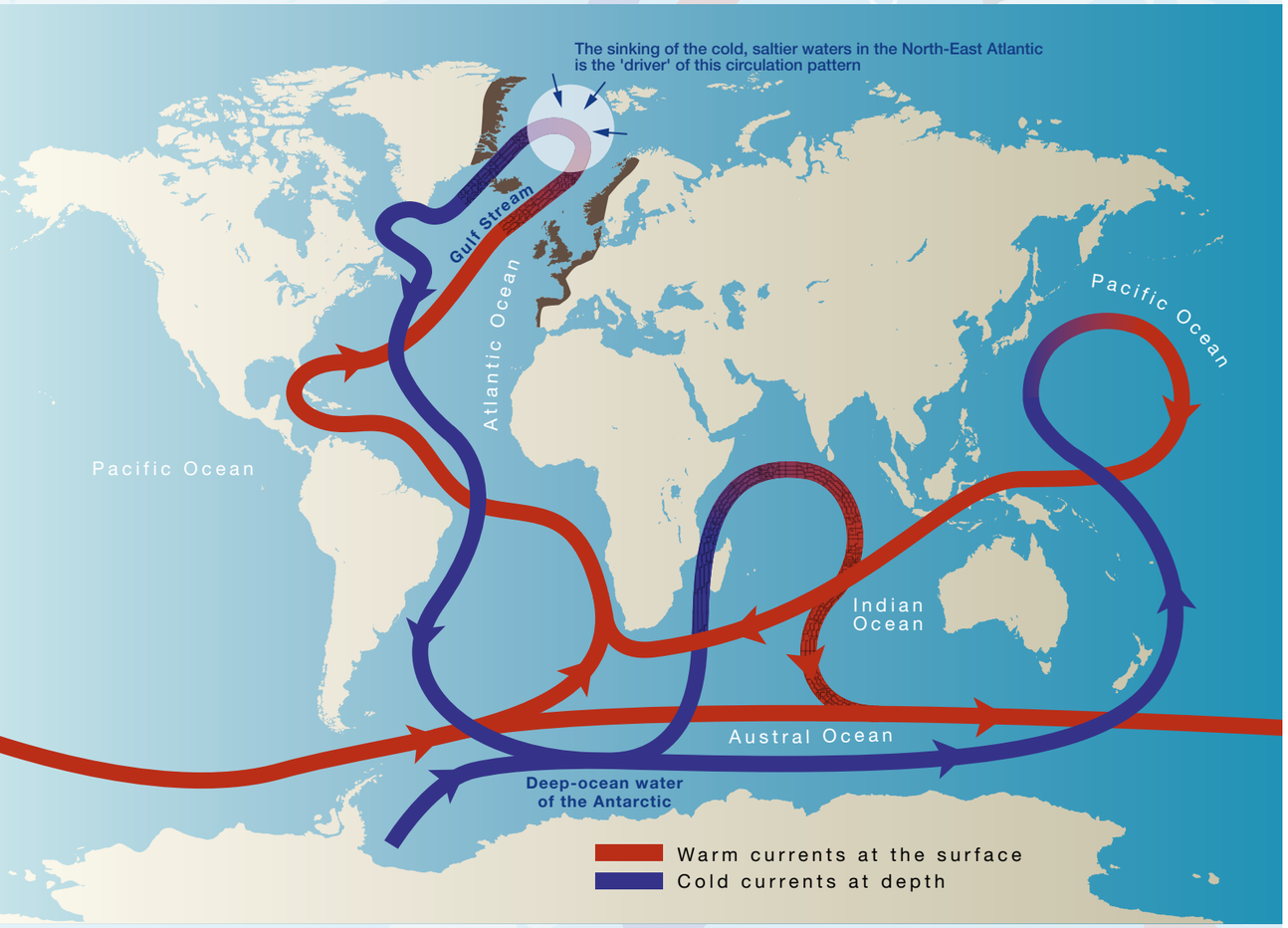
Main source: Glossary from the work: L'Océan à découvert, under the direction of Agathe Euzen, Françoise Gaill, Denis Lacroix, Philippe Cury, CNRS Éditions, 2017.

Macrophytes
All aquatic plants of large size (macroscopic size).

POWERFUL OCEAN CURRENTS
THAT REGULATE THE CLIMATE

The warm water at the surface *(in red)* and the cold water at depth *(in blue)* are displaced and create the large-scale ocean currents engendered by the differences in density of the seawater resulting from variations in temperature *(thermo)* and salinity *(halo)*. This is what we call thermohaline circulation. The cold, saltier water sinks down to the depths. The Gulf Stream is a warm current which flows from east to west in the North Atlantic: in *brown*, its zone of influence.

The thermohaline circulation has a very strong impact on patterns of changes in the climate, in particular in the exchanges with the atmosphere and the marine ecosystems, at several scales.



Sources: Broeker, 1991; Jean-Marc Jancovici, 2003.

>>

➔ CAN THE IMPACT OF CLIMATE CHANGE HAVE A CUMULATIVE EFFECT ON THE OCEAN AND ON MARINE BIODIVERSITY?

It's one hypothesis and a non-null probability that there may be synergy between the different stresses.

We don't yet know all the effects; but we can observe, for example, that the increase in temperature causes – we've already referred to this – the stratification of marine zones according to depth and that the thermohaline circulation resulting from the ocean dynamic occurs much more slowly. This also has considerable consequences for climate change.

➔ THE RAPID PROGRESSION OF CLIMATE CHANGE AND ITS EFFECTS HAVE REPERCUSSIONS FOR MARINE BIODIVERSITY. HOW DO THE SPECIES REACT?

We have to consider different species: those that we call vagile, such as the fishes which can move around in the Ocean, and thus migrate to more clement regions. For example, species in the Northern Hemisphere can migrate towards the Arctic [5].

So in terms of latitude, displacement is possible, but it is much more difficult in the vertical direction, for the species near the surface. The pressure [6] means that they cannot go down below the depth where they are used to living.

There are also all the bottom-dwelling organisms, what we refer to as benthic. They have no choice, they have to stay where they are. But in certain of them there is a life cycle with an adult phase when the animals are fixed, as is the case for the mussels through their byssus or the oysters, and a larval [7] phase during which the larvae migrate throughout the ocean before coming back to their starting point.

With regard to the larval phase, we have very little data to understand the real impact of climate change, except what is collected in the aquarium. But what we find *in vivo*, from the experimental point of view, and what happens in the Ocean - really *in situ* – is of course not comparable.

>>


Ph. Adobe Stock/Jarrod


Ph. Adobe Stock/gilimhanov

Because of the warming of the waters of the Atlantic, the king crab – a living resource of high economic value - has been invading the continental margin of the Antarctic peninsula. This species may soon cause serious damage to the biodiversity of that region.

(5) According to Elvira Poloczanska, of the Commonwealth Scientific and Industrial Research Organisation (CSIRO), the Australian equivalent of the CNRS, the displacement of marine species towards higher latitudes, in the north and in the south, is occurring "at a mean rate of 72 km per decade". More specifically, records show 470 km per decade for the phytoplankton, 277 km for bony fishes. The crustaceans, molluscs and the large algae are the slowest in their displacements (sources: Sciencesetavenirfr, Nature et environnement, 2013/Nature Climate Change, 4 August, 2013).

(6) The atmospheric pressure measured at the surface of the Earth is 1 bar, or 100 000 Pa (Pascal). The hydrostatic pressure varies according to the depth and increases by 1 bar every 10 metres of water depth.

(7) For example: the larval phase of the reproductive cycle of the mussel lasts from 3 weeks to 1 month

Focus

The Ocean, is:

71% of the surface of the planet

97% of the water on Earth

50% of the oxygen in the air we breathe

The Ocean is an essential regulator of the Earth's climate.
Since 1970, it has absorbed:

94% of the heat accumulated in the atmosphere due to the impact of greenhouse gas

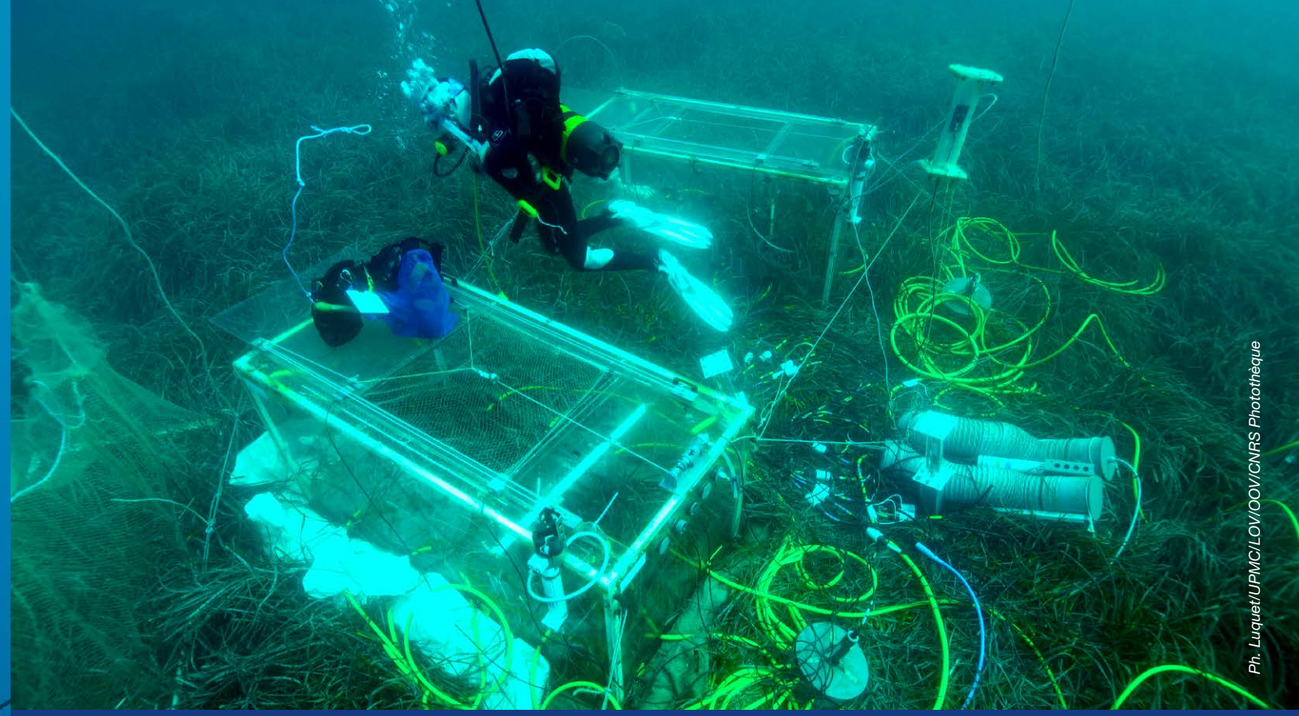
30% of the carbon dioxide produced by anthropic activities

Source: *Océan et climat, 2019* – Scientific factsheets. www.ocean-climate.org

Ph. D. Luquet/UPMC/LOV/CNRS photothèque

A mesocosm, a sort of large floating test tube, deployed in the north-western Mediterranean, in the bay of Villefranche-sur-Mer for a test experiment. Formed of a large 50 m3 plastic bag, it captures all the plankton. The concentration of carbon dioxide in the bag can be altered. Around fifty chemical and biological parameters can be measured, and samples collected.

For the MedSeA project (Mediterranean Sea Acidification in a changing climate), the aim is to determine whether the acidification of the seawater has an impact on the functioning and structure of the coastal plankton communities.



Ph. Luquet/UPMC/LOV/OOV/CNRS Photothèque

Projet eFOCE (European Free Ocean Carbon Enrichment project) *– This array of chambers is installed at a depth of 12 m to study the impact of acidification of the seawater on a Mediterranean* Posidonia oceanica *seagrass bed.*

Ph. C. BRUNET/CNRS Photothèque

Launching a rosette sampler on board the Marion Dufresne. The aim of the OISO (Indian Ocean Observation Service) measurement surveys, carried out in the south of the Indian Ocean, is to better understand the distribution of the sinks and sources of carbon dioxide at the surface of the oceans.

2/ Upgrading the science and knowledge on the Ocean - Climate - Biodiversity nexus

➔ ARE THERE SCIENTIFIC PROGRAMMES FOCUSED ON THE INTERACTIONS BETWEEN THE CLIMATE AND OCEANIC BIODIVERSITY?

In terms of fundamental research, there are a certain number of international programmes currently in progress. It is true that there is a difference between the oceanographers, who have a perception of the Ocean phenomenon that is more at a biophysical level, and the biologists and ecologists who are looking at the interactions between living organisms in a natural environment.

So these two scientific approaches differ. But that's just the point, the interest of what we are doing now with the Ocean - Climate - Biodiversity nexus is in pooling resources and developing interdisciplinary knowledge with the aim of determining the potential points of catastrophe, the points of no return, the tipping points*, which we must avoid reaching. It is a complex matter, and we should be focusing our efforts on this aspect without delay.

➔ IT IS SOMETIMES CLAIMED THAT KNOWLEDGE IS KEPT STASHED AWAY IN SILOS BY THE VARIOUS SCIENTIFIC DISCIPLINES. DON'T YOU THINK THAT TODAY THIS OCEAN - CLIMATE - BIODIVERSITY NEXUS CALLS FOR A NEW KIND OF TRANSVERSAL SCIENCE WHICH WE MIGHT CALL THE SCIENCE OF SUSTAINABILITY?

That is the whole question of interdisciplinarity that you've raised, what we call *sustainability science* (difficult to translate into French). But the idea, which comes incidentally from the strategy of sustainable development, is: *"Let's raise the questions that concern us regarding our way of life and our kind society, and let's see what solutions we, the scientists, can find"*.

➔ … SO WHAT SOLUTIONS CAN BE FOUND?

It can only be by breaking out of our academic mindset, because – and it's quite understandable – the power of scientific research is to be in a context where the rules of functioning and of the production of knowledge are marked out by history, by concepts, and follow a procedure. It is only on that condition that we can progress.

So as I've already said, we have to try with this sustainability science to see rather what is the question raised and to see what solution we can propose in response with the knowledge we possess, which is always infinitesimal compared to the vastness of the range of possibilities.

This new approach means that we can only move forward together, with other disciplines, and around a project. When you are an oceanographer, you know this because we could never have organised a major cruise without having a whole team with us, different laboratories and different countries.

Sustainability science goes much further [8] with regard to the major issues that we humans absolutely must find solutions to, such as climate change, the loss of biodiversity, the pollution and degradation of the land and the aquatic environment.

The Swedes, with their Resilience Centre [9], were among the first to make any progress on this issue. They are a long way ahead, the Americans too. In Europe, we must now make a leap forward. We are ready, and I think we can do it. This sustainability science, it's tomorrow.

(8) According to the Institut de Recherche pour le Développement *(IRD - Development Research Institute), "It is not just a matter of providing technical or scientific responses to tackle environmental crises. Sustainability science also integrates the ethical dimension, takes into account our responsibility with regard to future generations".*

(9) The Stockholm Resilience Centre is an international institute for research on resilience and sustainability science. Its mission is to promote research on the governance and management of socio-ecological systems in order to guarantee the ecosystem services for human wellbeing and resilience for long-term sustainability (source: www.stockholmresilience.org).

➔ WITH THE OCEAN AND CLIMATE PLATFORM, YOU ARE IN FACT ONE OF THE ACTORS OF THE UNITED NATIONS DECADE OF OCEAN SCIENCE FOR SUSTAINABLE DEVELOPMENT. WHAT IN PARTICULAR DO YOU EXPECT FROM THIS DECADE?

First of all, I would simply like to say that the fact of announcing this Decade has already generated an absolutely extraordinary dynamic.
The scientific community has at last been recognised as the bearer of values which go beyond academic research. This awareness is already extraordinary enough. The second thing is that France, thanks to this Decade, has managed to focus the attention of the world of politics on the Ocean, and that the President of France was thus able to announce the existence of a priority programme of research on the Ocean.

Ten years ago this would have been unimaginable. Ideas progress. This is the first time, to my knowledge, that France has been able to bring together all the actors in society engaged in the achievement of the Sustainable Development Goals: the scientific community – working in more applied academic environmental research – and the world of politics. The aim was to propose an Ocean route map for the Decade [see page 18: *What sustainable development for 2030?*].
We have made a lot of progress in a period of only six months, certainly because we have had the benefit of ten years of work upstream.

The launch of this Decade was a point of crystallization and a symbolic act. The whole community is abuzz to get organised, to see each other's point of view. I think it's extremely important.
Now in Europe we also have another organisation that is in the process of imagining how society might integrate the Ocean in a vision of the future

This is the Lamy mission which is focused on the Ocean, the seas, the coastal and continental waters, that is to say that it's the whole great water cycle – where the Ocean is the major element – which should be dealt with from the research point of view: not to obtain new results as such, but to see to it that research on the Ocean is really brought to the forefront to feed the imaginary of a European society of individuals, of citizens.

>>

Point of no return *(or* ***tipping point****) of the climate system.*

According to climatologists, warming could exceed a threshold beyond which irreversible effects would occur, repercussions in cascade, which would increase uncontrollably.


Ph. Adobe Stock/Jaro

Focus

WHAT SUSTAINABLE DEVELOPMENT FOR 2030?

A NEW ROUTE MAP FOR FRANCE

Ph. G. Bounaud

High level scientific conference at UNESCO Headquarters in Paris in preparation for the United Nations Decade of Ocean Science for Sustainable Development. Left to right: Françoise Gaill, Emeritus Director of Research CNRS, and Patricia Ricard, President of the Institut océanographique Paul Ricard, speaking in their role as session moderators.

UN Photo/Cia Pak

Before the United Nations Sustainable Development Summit (2015), presentation of Agenda 2030 and its 17 Sustainable Development Goals (SDGs), at the United Nations Headquarters, New York.

UN Photo/Rickey Felipe

High-level political Forum on Sustainable Development, 25 September 2019, at the United Nations – Tijjani Muhammad-Bande (centre, on stage and on screen), President of the 74th session of the United Nations General Assembly, emphasises the need to speed up the implementation of the Sustainable Development Agenda 2030.

In September 2015, the 193 member States of the United Nations Organisation (UNO) committed to contributing to the realisation of Agenda 2030 with its 17 Sustainable Development Goals (SDGs).

This Agenda was adopted after two years of negotiations involving both governments and civil society. It deals with the challenges facing the world today, related in particular to poverty, inequality, climate change, the degradation of the environment, peace and justice.

The Sustainable Development Goals are the follow-up to the **Millennium Development Goals (MDGs)** which covered the major humanitarian priorities – reducing poverty, hunger, disease, providing access to education - which targeted developing countries for the period 2000-2015.

Now that we are only 10 years away from the 2030 deadline, it can be seen that progress has been made in certain areas, but that this is still not enough.

In September 2019, the Secretary General of the UN invited all sectors of society to mobilise in favour of a far-reaching **Decade of Action** with the aim of achieving the goals within the deadline.

Following this appeal, France published **a new route map** to implement the **17 Sustainable Development** Goals (SDGs) of Agenda 2030. The action plan has adopted six priority aims: in particular, a fair transition, a low carbon society and savings of natural resources, to act in favour of the climate and the planet and its biodiversity.

This route map proposes to speed up the processes of progress with the aim of shifting our society towards a model that will be at once more prosperous, more inclusive and more environment-friendly, so that France will be among the countries to achieve the Sustainable Development Goals in 2030.

RECOGNITION OF THE ROLE OF THE OCEAN

Another important event in the international agenda and related to the previous ones is the launch on 3 February 2021 of the **United Nations Decade of Ocean Science for Sustainable Development** (2021-2030).

This decision confirms the increasing interest in the Ocean among the international community and the recognition of its major role in climate regulation. It calls for the support of the ocean sciences to implement the **Paris Agreement** and to achieve the Sustainable Development Goals fixed by Agenda 2030.

The Ocean and Climate Platform and the Intergovernmental Oceanographic Commission of UNESCO (IOC-UNESCO) organised on 10 and 11 September 2018 a high-level scientific conference*. This was a first event in the preparatory phase for the United Nations Decade of Ocean Science for Sustainable Development.

Source: *unenvironnement.org*
To find out more: *un.org., Le Monde.fr (15 November, 2019).*

(*) In partnership with the Agence Française pour la Biodiversité, Alliance Nationale de Recherche pour l'Environnement (AllEnvi), *the Canadian government,* Centre National de la Recherche Scientifique (CNRS), Fonds Français pour l'Environnement Mondial, *IFREMER, IRD,* Institut océanographique Paul Ricard, Alliance d'Initiatives Océan et Climat, *and* Université de Bretagne Occidentale.

Ph. Adobe Stock/peangdao

>>

➔ AS THE UNITED NATIONS DECADE OF OCEAN SCIENCE FOR SUSTAINABLE DEVELOPMENT GETS UNDER WAY, WHAT IS THE STATE OF OUR KNOWLEDGE OF THE OCEAN? ACCORDING TO CERTAIN EXPERTS, WE KNOW MORE ABOUT THE PLANET MARS.

We know 5% of the topography of the seabed, so virtually nothing. It's true that to explore the Ocean, you must have the means to do it and engage particular investments. Realising any project isn't so easy.
But I think that for sustainability and the strategy of the Sustainable Development Goals for 2030, the Ocean will be able to contribute enormously through the input of science, that is the knowledge of this environment, which represents most of the biosphere*, will enable us to make progress both on climate change scenarios and in our way of working [see page 18: *What sustainable development for 2030?*].

It's a matter of seeing to it that we achieve a reduction of biodiversity loss, or even a way to conceive the living world as a tool for the promotion of the quality of life on Earth.

> *"To conceive the living world as a tool for the promotion of the quality of life on Earth"*

➔ WHAT ARE THE ECOSYSTEMS THAT ARE MOST IMPACTED BY THE LACK OF DATA?

The deep sea, of course!
We know a lot about the first 700 metres beneath the surface. The International Panel on Climate Change (IPCC) has besides really marked this zone out well.

With the development of the new Argo buoys and various observation systems, we are beginning to get some data down to 2000 metres. But after that, there's a knowledge gap. At 3 000 metres, we know nothing at all! Nothing! I would almost say that at 4 000 metres we know a little more because of the fact that we have to know the topography of the ocean seabed to lay submarine cables.

> ***Sub-surface***
> *Zone immediately below the surface of a soil.*

➔ YOU OFTEN REFER TO THE NECESSITY OF RELAUNCHING DEEP SEA EXPLORATION. WHAT WOULD BE THE INTEREST?

I have already said, for example, how a drop of water comes back to same place after going around the world. But we have tracked only 10% of its route, the rest of the journey remains obscure. It's the same thing for the topography of the seabed, which we know virtually nothing about. You have to imagine that only three people have been down into the Mariana trench [10] in three quarters of a century. Yet we have all the technological means to go there.
But I think that there is something else: in most processes, we only skim the surface, we only see something that comes up from the dynamic of the deep itself. And then there is another idea, more poetic, which I love. It is that in my view, knowing the deep sea well [11], so far we've felt attached to the surface of the Ocean, firstly because it 's there that there's the most going on, but also because it is the only thing we see. All we know how to do is stay on this surface in relation with the atmosphere.

In contrast, for the deep, the atmosphere is not the hard core. Working on hydrothermal vents, I would say that it's the centre of the Earth. And in my view, it's almost as important as the sun: that is to say its energetic power means that there are a certain number of events which drive the dynamic of currents, but also of heat and oceanographic phenomena, which we know nothing about at present.
In the future, these events will have an impact on our understanding of climate change. This is true for the phenomena that I would qualify as macro, but there is also everything that happens in the sub-surface*: there is an ocean crust below which a whole world of micro-organisms could be in reserve and may have extraordinary properties that might be of interest for the living world in the future.

>>

(10) Situated in the North-West Pacific Ocean, to the east of the Mariana islands, near the island of Guam, this is the oceanic trench that is recognised as the deepest place on Earth: 10 994 m depth at its lowest point with a pressure of more than 1 100 atmospheres (1 atm at the Earth's surface).

(11) Françoise Gaill has organised around thirty French and international oceanographic cruises. This oceanaut has dived in many oceans worldwide, in exploration submarines. For example, in 1996, she took part in the survey Hot 96 on board the Nautilus, at 2600m depth on the North-East Pacific dorsal ridge. Her research and publications are focused in particular on deep ocean environments and the adaptation to extreme environments.


Ph. Adobe Stock/photopoint


Ph. Adobe Stock/A. Lesik

Maritime transport carries more than 90% of goods worldwide and several million cruise passengers every year. According to France Nature Environnement, *each of these 'monsters of the seas' generates as much ultra-fine particle pollution as a million cars. The International Maritime Organisation (IMO) has adopted a plan to reduce greenhouse gas emissions by at least 50 % by 2050.*


Ph. Adobe Stock/A. Kuzmin


Ph. Adobe Stock/Wichaiwish

Human activities are the cause of the introduction of a range of polluting substances into the Ocean: pollution by plastics, urban sewage, etc.

>>

➔ WHAT IS THE STATE OF HEALTH OF THE OCEANS TODAY? YOU HAVE SAID THAT THE SURVEY PRESENTED BY THE SCIENTIFIC COMMUNITY IN THE LATEST IPCC REPORT ON THE OCEAN AND THE CRYOSPHERE IS 'BRUTAL': IN WHAT SENSE?

The Ocean is in a very bad way around the edges:
- at the surface where we travel, since the maritime traffic is after all the most important economic sector as concerns transport;
- in the littoral, where everything that comes from the earth goes into the sea, and where everything that is polluting is ultimately discharged into the sea.
In this respect, today plastic is omnipresent and we talk about it endlessly. It is among us like a natural element, whereas there are plenty of chemical substances that we don't even see and which we don't yet know how to identify in the sea. These are real cause for concern for the future.

> *"That means in fact that there are areas where there is no future"*

➔ DO YOU THINK THAT WE HAVE ALREADY REACHED, AS SOME SAY, THE LIMITS OF THE IRREPARABLE, THE IRREVERSIBLE EVEN, IN TERMS OF CLIMATE CHANGE AND THE COLLAPSE OF MARINE BIODIVERSITY?

I would say that there are places where that is the case. For example, look at what happened to the Newfoundland fishery in the 1980s: the fish stocks never came back; they disappeared, and that was it [12]. So that means that there are areas where there is no future.
But it's not true for other regions. For example, there is at the moment a great debate about the corals.

Concerning the Australian Great Barrier Reef, the Intergovernmental Panel of experts on climate change rightly insisted on the dangers of climate change and said that if it continued, we would reach a critical tipping point* which would annihilate the regeneration of the corals.

Other schools of thought report observations of small coral reef islands that are less altered, scattered around a sector near the Great Barrier Reef, which might be a source of regeneration for the damaged corals [13].
Setting aside the discussions, the Great Barrier coral reef is to me something we must look at and try to protect to the best of our ability. And as far as that protection goes, we have a real problem.

Furthermore, UNESCO is currently observing with attention the changes in this great reef, since it's true that areas identified as common heritage of humanity are not necessarily recognised as such.

➔ THE IMPACT OF CLIMATE CHANGE AND THE PRESERVATION OF MARINE BIODIVERSITY: THE CASE OF THE GREAT BARRIER CORAL REEF MAY BE CONSIDERED IN TERMS OF THE MANAGEMENT OF THE COMPONENTS OF 'OUR' NEXUS. MORE GENERALLY, WOULDN'T IT BE A GOOD IDEA TO ENVISAGE BRINGING TOGETHER THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE AND THE INTERGOVERNMENTAL SCIENCE-POLICY PLATFORM ON BIODIVERSITY AND ECOSYSTEM SERVICES (IPBES)?

The interesting thing is first of all that there is not one biodiversity but many different types of biodiversity. And if there is an issue that needs resolving, it's the fact that biodiversity is not only the description and the classification of species, the taxonomy. It's also the diversity of habitats, of the functional traits* of species, compared to each other. Finally, it's the way the environment can also play a role in the development of the living world.

Glossary

Functional trait
Any morphological, physiological or phenological characteristic of an organism measurable at the scale of individuals and which affects its individual performance. At ecosystem scale, the functional traits are responsible for the way organisms respond to environmental factors (source : https://fr.wikipedia.org).*

Phenology
Study of the appearance of periodic events in the living world - usually annual - determined by seasonal variations in the climate.

Habitat
Geographical environment specific to the life of an animal or plant species.

So there is a broad area which is currently under discussion and which is also an expression of the closer relation with the climate. If there are biodiversities, while there is only one climate, how are we going to manage to work together? I think there are various possible ways forward, but the notion of habitat* is essential.
Habitat means that a physical environment such as the Ocean can be altered not only by climate change, human activities and so on, but also by the living organisms that live there and that change the physical and chemical conditions of the environment. This aspect has hitherto been underestimated.

>>

(12) From the 1970s-1980s, a brutal collapse of cod stocks occurred off the coasts of Newfoundland. This case of overfishing remains emblematic of the failure of the policies of management of living resources.

(13) According to a study published in the journal PLOS Biology – based in San Francisco (USA) and Cambridge (United Kingdom) – a hundred or so coral reefs appear to have been less exposed to the devastating effects of bleaching. And these reefs are linked to much of the Great Barrier Reef by the ocean currents. This means that "these corals have the potential to procure the larvae indispensable for the restoration of the other damaged reefs", report the researchers at the University of Queensland, Australia (source: Coral Reef Ecosystems under Climate Change and Ocean Acidification. Ove Hoegh-Guldberg and al. - Front. Mar. Sci., *29 May, 2017).*


Ph. Adobe Stock/Shota
Ph. Adobe Stock/superjoseph

The Great Barrier Reef (Australia) is the largest coral system in the world. Extensive areas have been impacted by severe bleaching and a massive mortality of the corals (see photo above) due to recent heatwaves.

3/ Solutions to meet the climate challenge and preserve biodiversity. Which actors, what actions?

➔ IN TERMS OF SOLUTIONS, CAN WE SAY THAT KEEPING AN OCEAN IN GOOD HEALTH IS PRIMORDIAL FOR LIMITING THE IMPACT OF CLIMATE CHANGE ON MARINE BIODIVERSITY?

It's essential, and it really should be our first priority for the future, from the point of view of sustainability. It would take a thousand years, remember, for our drop of water to make its way around the planet and come back to the same point in the Ocean. That's a very long time.

For climate change, which is also something very slow, we need the Ocean try to focus, in the long term, the improvement that we can bring to the planet.

> *“Work towards a situation where we'll have an Ocean that is sound and healthy”*

➔ REFERRING TO THE COLLAPSE SCIENCE OF THE LIVING WORLD, COLLAPSOLOGY, CAN WE STILL MEET THE CLIMATE CHALLENGE AND PRESERVE BIODIVERSITY?

Yes of course. It is not because there are critical points here and there, catastrophic moments, that the situation is irreversible.

I think that we are not at the end of life on Earth, today, and that the Ocean has a capacity for resilience that we cannot even imagine.
On the other hand, we must work towards a situation where we'll have an Ocean that is sound and healthy, because that would mean a protected climate [14].

We should think about how to find solutions and strategies. There are no key-in-hand solutions, except perhaps reducing all our carbon dioxide emissions. That's the be-all and end-all of any initial action.

➔ AT COP 25, THE OCEAN AND CLIMATE PLATFORM PRESENTED A 2019-2021 APPEAL FOR 'A HEALTHY OCEAN, A PROTECTED CLIMATE'. DID THIS DOCUMENT PROPOSE SOLUTIONS TO PRESERVE THE OCEAN AND ITS BIODIVERSITY IN THE CONTEXT OF CLIMATE CHANGE?

This appeal proposed some suggested approaches. For example, we insist absolutely that the notion of marine protected areas (MPAs) be defended and that it should be seen as an important tool for the regulation of climate change. But the MPAs are also places which will enable us to have reserves of biodiversity if they are very well managed. In the future, these protected areas could be what I call potential dissemination zones, since one of the major problems is the interconnection between the different marine areas.

➔ THAT'S TO SAY?

If a protected area presents a reserve of living organisms in good health, it can have a positive impact on a protected area situated a bit further away through a process of colonisation* by certain species. So this process of dissemination could contribute to the emergence of a healthy and resilient ecosystem.

(14) To find out more: Ocean and Climate Platform, Policy recommendations: A healthy Ocean, a protected climate. December 2019

➔ DO YOU THINK THAT THE FIGHT AGAINST CLIMATE CHANGE AND MARINE BIODIVERSITY LOSS CONSTITUTES TODAY A GLOBAL ISSUE WHICH HAS AT LAST FOUND ITS RIGHTFUL PLACE WITH REGARD TO THE FUTURE OF OUR SOCIETIES?

Absolutely, and it's really the Ocean - Climate - Biodiversity nexus that we should consider. We have done a lot of work on the climate, now we should focus on the climate - biodiversity relationship.
I would say that this is in phase with history, since initially the Intergovernmental Panel on Climate Change (IPCC) was founded because the climate sciences were a long way ahead compared to the other disciplines. And it's nearly twenty years later that the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) has now been set up.
We can clearly see where we are heading, and simply to link up these bodies in particular seems absolutely necessary.

> *“It's really the Ocean - Climate - Biodiversity nexus that we should consider”*

➔ SHOULD THERE BE A RESPONSE AT PLANETARY LEVEL ? ARE WE ON THE WAY TO A GLOBAL SYSTEM OF MANAGEMENT?

Yes, we need a response at planetary level as regards the position to adopt. But the whole difficulty, the challenge we are facing, is to succeed in articulating the global and the local.
There is a range of local solutions, families of solutions, not just one. But what we must agree about, at global level, is the principles. And if there is agreement, then diversity goes without saying in relation to the local.

➔ WHO ARE THE VARIOUS ACTORS?

I think that it's a whole range of deciders, scientists, NGOs, who should work together.
The political authorities in the sense of the State should intervene regarding the general principles of the United Nations, since the governance must be at planetary level. On the other hand, for putting them into practice, everyone should have their say.

Glossary

Dissemination zone
Exportation of larvae, juveniles or adult individuals from protected areas.

Colonisation
In biology, a process by which a species spreads into new habitats.

For example, it's through negotiation that we could find intergovernmental agreement for the treaty referred to as BBNJ (Biodiversity Beyond National Jurisdiction) on the conservation and sustainable use of marine biodiversity beyond national jurisdictions [15].
That means that there should be a framework defined by the States with real negotiations because the scientists should have their say, but also the NGOs, companies, business interests, and each should play their role.
For example, the scientists' position is based on what is known as a common core of knowledge and understanding of phenomena, and they propose a range of solutions. But it's not they who have to put these solutions into application, but those who are in a position to act, such as the NGOs, because they come from civil society, and companies which possess certain advantages and disadvantages for exploiting this knowledge.
But I think that for any action at sea, there should as a matter of principle be an expert assessment by the scientists to determine the risks of environmental impact.
I think too that this impact study should be discussed by the whole of civil society with business leaders and the State to provide information about it and discuss it. Then it'll be up to the States to take responsibility.

> *“We need a response at planetary level”*

>>

(15) For this future international agreement, a schedule for negotiations was decided on in 2018, with 4 themes: marine genetic resources, tools for the protection of marine biodiversity, in particular the Marine Protected Areas (MPA), assessment of the environmental impact of new human activities on the high seas, strengthening of the capacities and transfer of marine for the benefit of developing States.
(source: diplomatie.gouv.fr).
To find out more: What governance for the Ocean? - Interview with Serge Segura, ambassador of France for the Oceans, Institut océanographique Paul Ricard Newsletter n° 16, 2018, p. 14.

11 March, 2020 – Meeting of the United Nations General Assembly on the conservation and sustainable use of marine biological diversity in zones situated beyond national jurisdictions.

*First conference on the oceans at the Headquarters of the United Nations, 5 to 9 June, 2017, to support the implementation of Goal 14 of the Sustainable Development Agenda 2030 : «*Conserve and sustainably use the oceans, seas and marine resources*» for sustainable development purposes. Photo : pre-conference press briefing, H.S.H. Prince Albert II of Monaco (centre); on his right, Françoise Gaill.*

'Fridays for Future'*: on Friday, 20 September, 2018, hundreds of thousands of young people throughout the world were mobilised for the climate. Among the slogans:* «There is no planet B». *It was the young Swedish militant Greta Thunberg who started this movement.*

>>

➔ WE OFTEN SPEAK OF 'THE OCEAN, COMMON GOOD OF HUMANITY'. COULD THIS NECESSITY OF WORKING ON THE OCEAN - CLIMATE - BIODIVERSITY NEXUS ALSO ENABLE US TO RETHINK OUR DIPLOMACY, OUR INTERNATIONAL RELATIONS?

It's a very complex question, and I think it's very important to use this concept: 'The Ocean, a common good of humanity' as a goal, since it establishes values. And it is first of all a human position of importance, which entails the introduction of a dimension which is not there in the science: responsibility.
For example, the work which has been done for water at the United Nations on this notion of 'common good of humanity' was put on hold for political reasons. To get it reactivated would be in phase with the times.
For the Ocean, right in the middle of the negotiations for the BBNJ treaty [15], this is really the right moment to get the States to work on this issue, which is not a legal question.
We have a great responsibility to bear in mind that the legal aspect, which certainly has a right to exist, is not there to provide the means of expression to dimensions such as responsibility that the notion of 'The Ocean, common good of humanity' can induce. The fact of remembering our own moral values seems to me to be of the greatest importance.

➔ WITH THIS WORLDWIDE DYNAMIC, IS IT POSSIBLE TO AWAKEN A KIND OF UNIVERSAL AWARENESS?

Yes, we've seen it for the climate.
At the time of COP 21 [16], there was really for the first time a planetary-scale awareness of an event of a new type, which wasn't a war, but a deadly danger, climate change.
And then, look at what's happening today: the new generations, the young, are there to remind their elders that they have a future, and it must be taken into account.

➔ SO THIS INCREASED AWARENESS AMONG THE YOUNGER GENERATIONS IS OF CAPITAL IMPORTANCE?

Essential, and I feel fairly positive regarding their action and their capacity to create potential solutions for the future.

(16) The 21st Conference of Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC) in 1992 brought together 195 States and the European Union. The signing of the Paris Agreement marked a step in the fight against climate warming since it committed all the countries in the world to reducing their greenhouse gas emissions and keeping the temperature increases below 2°C up to 2100.

➔ AMONG THE - LET'S SAY - MORE PRACTICAL SOLUTIONS, CAN MARINE BIODIVERSITY CONTRIBUTE TO MITIGATING THE CONSEQUENCES OF CLIMATE CHANGE? NATURE-BASED SOLUTIONS ARE OFTEN PUT FORWARD, AND IN PARTICULAR *BLUE CARBON*. HOW EFFECTIVE IS IT, IN YOUR OPINION?

To answer your question, I'll refer back to the discussion I had at the Intergovernmental Oceanographic Commission (IOC) on the subject of blue carbon. What this United Nations body has said is very interesting: the notion of blue carbon* is political and not scientific! This shows the gulf that exists between how to assess blue carbon and the distance between knowledge and politics.
For me, a biologist, carbon depends on the atoms it surrounds, and the carbon dioxide is not necessarily of the same order according to whether it is in gas, liquid or solid form, whereas in the notion of blue carbon, we act as if everything is the same under the label carbon dioxide.
And if we put this carbon dioxide in the sea, there is some that sinks to the bottom for physical reasons concerning the current, and there is some that is used by living organisms. They absorb this gas and transform it. Carbon dioxide is almost a food it has need of. The plankton, for example, couldn't develop without this gas.

This story of blue carbon is perhaps complex to deal with. And before reducing it to a tonne of carbon emitted or assimilated, there's a whole spectrum of understanding that remains to be tackled and which has not been so far.
Everyone thinks that you can weigh a tonne of carbon on a balance. But what carbon are we talking about? The carbon that comes out of chimneys? The carbon that comes from other emissions, and if so which? So the fact of adding 'blue' to carbon, of course that makes it bluer, but the scientific significance remains uncertain.

➔ IS THERE A CARBON ECONOMY, A MARKET?

If there is a market for carbon, I'm for it, because for the moment it doesn't exist. In any case, it's so small that it doesn't necessarily have any real economic importance.
If it really existed, the carbon market would induce a paradox. Certain States - which because of their geography and their importance as major oceanic countries - might claim to use the capacity of their marine areas to stock carbon dioxide in order to account for it and discount it from their national carbon budget. This would enable States to avoid having to reduce activities with regard to the classic emissions of greenhouse gases.

Blue carbon
It refers to carbon dioxide removed from the atmosphere by the whole of the coastal oceanic ecosystems, mainly the mangroves, the seagrass meadows and the large laminar algae (macroalgae).

And there, there is a political problem to resolve which plays on - I repeat - this incomprehension regarding the diversity of meanings given to this term carbon. In this regard, a sense of concern has already been expressed by a certain number of countries. This must be taken into account.

➔ IN THE END, CAN WE BELIEVE IN A POWER OF RESILIENCE IN NATURE, HUMANS INCLUDED, TAKING INSPIRATION FROM INNOVATIONS WHICH HAVE BEEN DEVELOPED OVER BILLIONS OF YEARS?

Yes, we are a good example, because we constantly develop a range of new solutions, try to find resilience. But the Ocean, where life originated, contains all the potentialities that can develop in a liquid environment.
The degree of liberty enjoyed by living organisms in the Ocean is, in my opinion, much greater than what there has been on Earth. Simply, we don't have the opportunity to really appreciate it for what it is.

> ***"We have forgotten this relationship with nature"***

➔ HOW CAN EACH OF US BE REALLY INVOLVED AND PROVIDE SOLUTIONS? SHOULD WE REALLY RETHINK OUR RELATIONSHIP WITH THE WORLD?

We must realise that we have forgotten this relationship with nature because the urban environment we inhabit increasingly drives away our awareness of what nature is. And I think that is the great danger.
Going to see nature is the first thing to do for future generations, and not just to imagine it, but to feel it, to experience it, to take inspiration from it. And it's by observation that perhaps curiosity can emerge, which may be expressed in a thousand different ways, but one, the most difficult, the least baroque, is science. ■

Interview with Christian Frasson-Botton
The interview with Françoise Gaill was carried out at the Maison des Océans, Institut océanographique – Fondation Albert Ier, Prince de Monaco
February 2020

Focus

www.ocean-climate.org

OCEAN AND CLIMATE PLATFORM

MOBILISING THE ACTORS INVOLVED IN OCEAN ISSUES FOR THE OCEAN - CLIMATE - BIODIVERSITY NEXUS

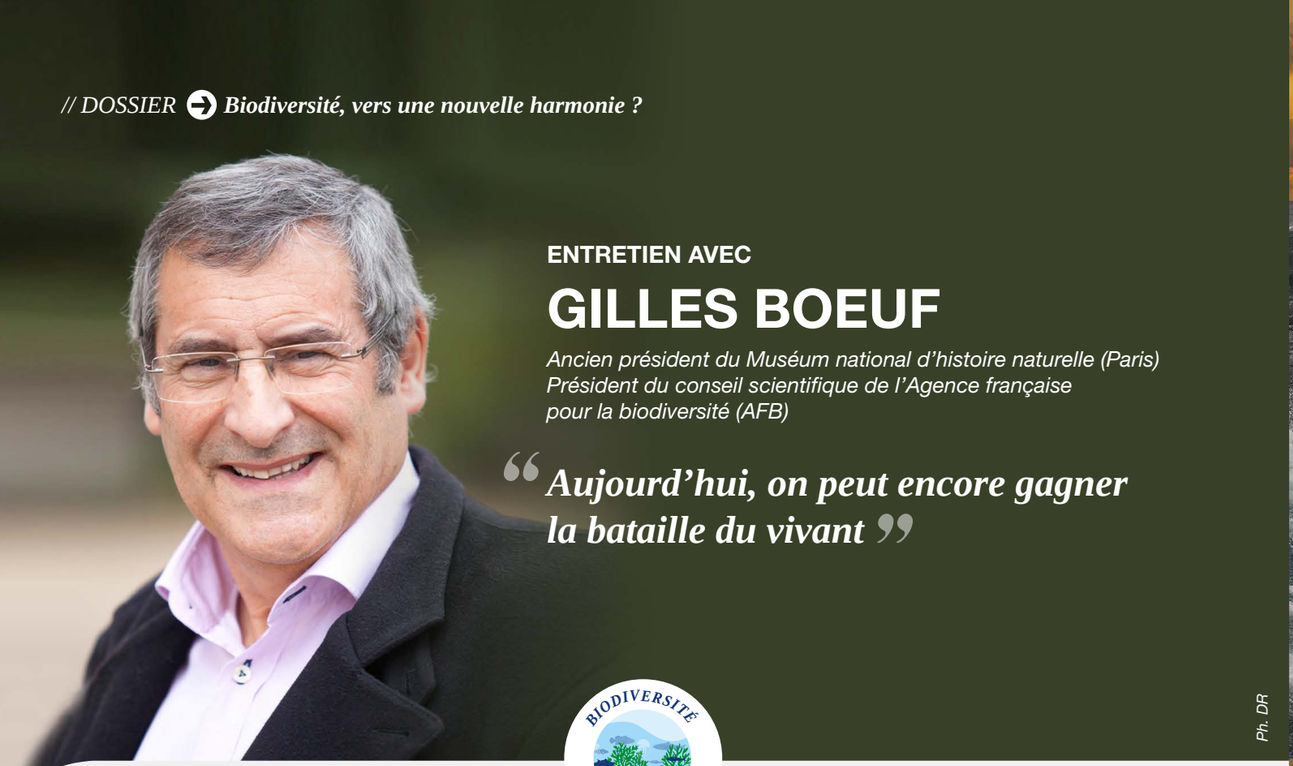
"The Ocean and Climate Platform is an ensemble of actors dedicated to action focused on the relationship between Ocean and climate. It was set up on 10 June 2014 on the occasion of World Ocean Day, with the support of the UNESCO Intergovernmental Oceanographic Commission.
It is an international coalition with some 70 members: many of them scientific institutions, such as the *Institut francais de Recherche pour l'Exploitation de la Mer* (IFREMER - French Research Institute for the Exploitation of the Sea), as many NGOs, small or large, aquariums, such as Nausica*á* and Océanopolis, representatives of oceanographic surveys such as Tara, and private-sector actors involved in the *Cluster Maritime Français* (CMF-French Maritime Cluster) or *Armateurs de France* (French shipowners), and public sector organisations such as the *Agence Francaise de la Biodiversité* (AFB) *and Terres Australes et Antarctiques Françaises* (TAAF - French Southern and Antarctic Lands), international United Nations organisations : UNESCO, the International Atomic Energy Agency (IAEA), the International Organisation for Migration (IOM).
Why did we set up this platform? The idea was simple. Before COP21, the Ocean had never been present in the negotiations. During twenty Conferences of Parties, there was a lot of talk of forests, but not of the Ocean. The word was pronounced at the very beginning of the first text at the first COP, then nothing.
So our idea was to promote the Ocean in these negotiations, as it plays a major role in the exchanges with the atmosphere and in the climate system. The idea was also to promote knowledge on the Ocean among scientists but also within society. Furthermore, it was a matter of bringing together all the actors involved in issues related to the sea to focus on the problem of climate change".

Extract from the hearing by Dr Françoise Gaill, Chair of the Strategic and Scientific Council of the French Oceanographic Fleet, coordinator of the Scientific Council of the Ocean and Climate Platform, in the frame of the Information-gathering mission on the management of major climatic events in the littoral zones of France and Overseas France. *Assemblée Nationale*, 17 January, 2018.


Ph. A. Wimmer

Françoise Gaill and Patricia Ricard, Vice-Presidents of the Ocean and Climate Platform.


Ph. Fotolia / I. Chaikovskiy



Ph. DR

ENTRETIEN AVEC

GILLES BOEUF

Ancien président du Muséum national d'histoire naturelle (Paris)
Président du conseil scientifique de l'Agence française pour la biodiversité (AFB)

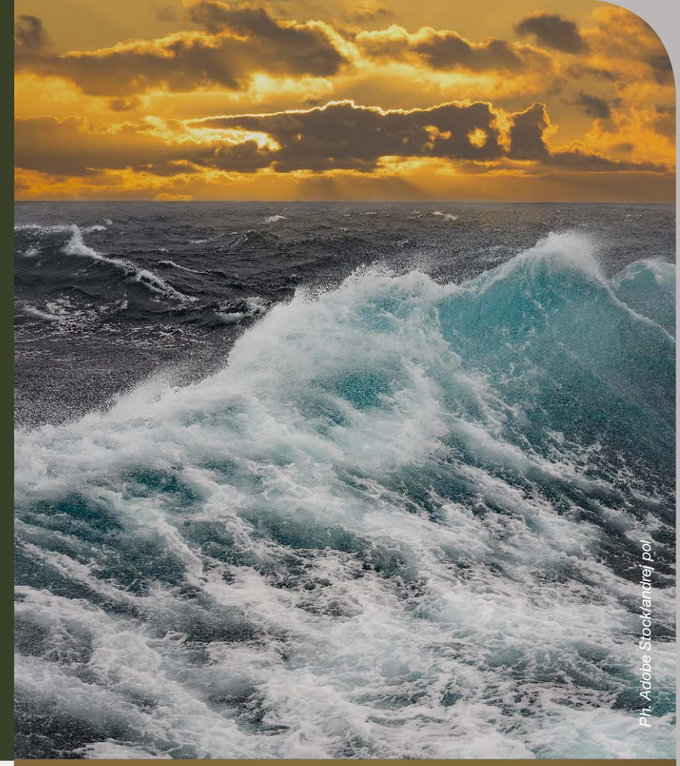
> *« Aujourd'hui, on peut encore gagner la bataille du vivant »*

BIODIVERSITÉ
EFFONDREMENT OU NOUVELLE HARMONIE ?

1 /
L'OCÉAN PRIMITIF, BERCEAU DE LA VIE.
ÉVOLUTION ET EXPLOSION DE LA BIODIVERSITÉ MARINE

2 /
EFFONDREMENT DE LA BIODIVERSITÉ MARINE,
LES FACTEURS ET LEURS EFFETS

3 /
LES MOYENS D'ENRAYER L'EFFONDREMENT
DE LA BIODIVERSITÉ MARINE



Ph. Adobe Stock/andrej pol

Ph. Adobe Stock/creativenature.nl

Macareux moine, Fratercula arctica *– Surnommé « perroquet de mer », ses ailes lui permettent de nager efficacement pour pêcher en apnée à 10 ou 15 mètres sous la surface. Il peut parcourir 50 mètres en 10 secondes avant de revenir à terre le bec chargé de prises pour son unique poussin.*

PARCOURS

1950
Naissance à Paimboeuf (Loire-Atlantique).

1978
Maîtrise en zoologie.

1979
Directeur de Recherche au CNEXO, l'ex-IFREMER, Brest.

1987
Doctorat d'État ès-sciences naturelles à l'Université de Brest.

1999
Professeur de physiologie à l'Université Paris 6, Directeur de l'Observatoire de Banyuls-sur-Mer.

2009
Président du Muséum national d'histoire naturelle, Paris.

2013
Professeur invité au Collège de France.

2015
Conseiller scientifique au cabinet de Ségolène Royal, alors ministre de l'Environnement, de l'Énergie et de la Mer.

2017
Président du conseil scientifique de l'Agence française pour la biodiversité.

Ph. Adobe Stock/whitcomberd

Exubérance du vivant dans ce récif corallien des îles Similan (sud de la Thaïlande) – Cet archipel détient un statut de parc national depuis 1982. Ses plages sont généralement des lieux de ponte pour les tortues.

Ph. Adobe Stock/Chris

Baleine à bosse, Megaptera novaeangliae *– La mère reste généralement près de son baleineau. Elle l'allaite pendant plusieurs mois, elle l'aide à venir respirer à la surface et le protège d'éventuels prédateurs. Les baleines sont particulièrement sensibles aux effets du changement climatique qui met en danger leur reproduction.*

1/ L'Océan primitif, berceau de la vie. Évolution et explosion de la biodiversité marine

➔ QUELLE EST L'ORIGINE DE LA VIE SUR NOTRE PLANÈTE ? Y A-T-IL UN MYSTÈRE DE LA VIE OU EST-ELLE LE FRUIT, L'ABOUTISSEMENT D'UN PROCESSUS CHIMIQUE ?

C'est tout cela. En fait, il y a deux grandes idées qui s'opposent.
Un prix Nobel de médecine, de nationalité belge, Christian de Duve, écrit en 1996 dans son ouvrage *« Poussière de vie – Une histoire du vivant »* que la Terre était si idéalement placée par rapport au soleil que la vie ne pouvait pas ne pas y apparaître. Pour lui, c'était l'évidence. À l'inverse, Jacques Monod [1] – autre prix Nobel –, disait : *« Quelle hypothèse improbable ! »*.

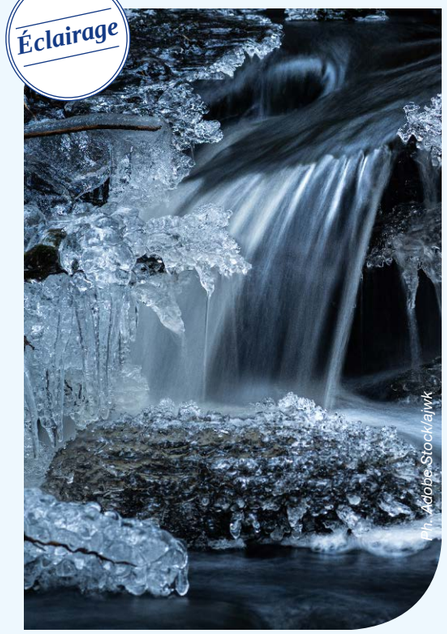
Ce qui est clair, c'est que la vie a absolument besoin d'eau liquide. Et si elle est apparue sur la Terre c'est parce que l'eau s'y rencontre sous les trois formes [2], dont la liquide. Il y a de l'eau en abondance sur Mars, mais c'est de la glace.

L'eau est la molécule initiale du vivant. Je rappelle qu'à la naissance, un bébé humain c'est trois-quarts d'eau liquide. Toutes les cellules de la vie, quelles qu'elles soient, sont constituées d'eau liquide. Ceci est très important.

Eau liquide… Cela veut dire une gamme de températures, puisque l'on sait qu'à 100°C et à une température d'une atmosphère*, l'eau bout et devient vapeur d'eau. À 0°C, l'eau se transforme en glace.

> *“ L'eau est la molécule initiale du vivant ”*

Éclairage



CONGÉLATION DE L'EAU
À QUELLE TEMPÉRATURE ?

La congélation (ou point de fusion) est le passage de l'état liquide à l'état solide par refroidissement. Elle dépend de la température, de la pression atmosphérique et de la concentration en sel.

• **L'eau douce liquide** devient de la glace à 0°C et à une pression normale quand la masse d'eau est homogène.
Mais dans le cas de rivières, où l'eau est plus ou moins agitée, il faut des températures négatives dont la valeur dépend de plusieurs facteurs qui sont variables d'un cours d'eau à l'autre : mélange des eaux, surface d'échange avec l'air, température du sol, quantité de substances dissoutes… Aucune étude scientifique n'a pu donner un ordre de grandeur général. Des archives canadiennes signalent que l'eau très agitée des chutes du Niagara n'aurait jamais gelé entièrement… même quand la température est passée sous la barre des - 40°C.

Cependant, en 2011, une étude parue dans la revue *Nature* apporte un autre éclairage sur la cristallisation de l'eau : elle ne serait pas seulement liée à une question de froid extrême, elle dépendrait aussi de la façon dont s'organisent les molécules d'eau. Des simulations montrent que l'eau pure doit atteindre une température de -48°C pour avoir un taux maximal de cristallisation et geler obligatoirement.

• **L'eau de mer** gèle à une température inférieure à 0°C, qui dépend de sa concentration en sel. Ainsi, l'eau de mer se prend en glace à -1,86°C pour une salinité moyenne de 35g/l.

Sur le continent, le vivant est donc forcément limité à une plage de températures de l'eau douce, entre 0 et 100°C. Mais la vie se manifeste aussi dans certains milieux marins à des températures très basses ou très hautes :
- dans des glaces extrêmement anciennes, en Antarctique, jusqu'à - 89°C [3] ;
- dans des sources hydrothermales, avec des températures largement supérieures à 100°C (autour de 140-150°C), puisqu'avec les pressions gigantesques de ces milieux profonds, l'eau ne peut rester qu'à l'état liquide à de telles températures.

Ainsi, la vie a trouvé une plage thermique idéale pour son développement.

> *“ Une vie avant la vie, qui est forcément issue de la chimie ”*

➔ PLUS PRÉCISÉMENT, COMMENT EST APPARUE LA VIE ?

L'émergence de la vie provient forcément d'une chimie antérieure. On parle d'ailleurs, effectivement, d'une vie prébiotique, d'une vie avant la vie, qui est forcément issue de la chimie.

Je crois que la plus belle relation que l'on puisse établir, c'est ce qu'on appelle une cellule : une petite sphère vivante entourée par une membrane, qui délimite un espace extérieur – en l'occurrence, au début, l'eau de mer –, et un espace intérieur. Et il se passe des choses entre les deux : on discute, on échange…

Cette membrane peut être composée par de la chimie : on connaît des micelles*, des petits lipides qui fabriquent spontanément des sphères. Et dès le moment où les cellules ont fabriqué cette membrane, elles sont devenues capables de se couper en deux pour donner deux cellules identiques.

Au départ, la vie se présente donc sans différenciation sexuelle. Le vivant se multiplie par scissiparité : la cellule – une bactérie, par exemple –, se divise et donne deux cellules filles, copies exactes de la cellule mère. Et ceci grâce à la réplication* de l'ARN* ou d'un ADN*, en fonction du type de cellule [voir en page 30 : *Reproduction – Asexuée ou sexuée ?*].

Glossaire

Atmosphère (atm)
Unité de mesure de pression : 1 atm est égale à 1,01325 bar.

Micelle
Très petite particule solide en suspension dans une solution composée d'un agrégat de molécules.

Réplication
Mécanisme de production de nouvelles molécules nucléiques d'ADN ou d'ARN.

ARN (acide ribonucléique)
Molécule qui transporte l'information contenue dans le patrimoine génétique (ADN) d'une cellule jusqu'aux ribosomes qui sont chargés de la traduire en protéines ayant des fonctions précises.

ADN (acide désoxyribonucléique)
Support de l'hérédité, c'est un long filament formé de la succession de quatre nucléotides différents – adénine, guanine, thymine et cytosine –, qui s'enroulent en une double hélice. Celle-ci est repliée sur elle-même sous la forme de chromosomes et se situe dans le noyau de chaque cellule.

À ce stade primitif de l'évolution du vivant sur la Terre, nous nous situons à quelques milliards d'années en arrière. Puis vers un milliard et demi d'années, un autre fait exceptionnel se produit dans l'Océan ancestral : l'apparition de la sexualité.

Le sexualité c'est quoi ? C'est deux cellules qui s'échangent du matériel génétique. La cellule résultante, issue de leur relation, n'est pas une copie de l'une ou de l'autre, mais un mélange des deux [voir en page 30 : *Reproduction – Asexuée ou sexuée ?*]. C'est extrêmement fort pour faire de la biodiversité.

>>

(1) Prix Nobel de physiologie ou médecine, Jacques Monod est l'auteur d'un essai intitulé « Le Hasard et la nécessité. Essai sur la philosophie naturelle de la biologie moderne », *1973, Editions du Seuil. Ce titre est tiré d'une citation que le biologiste attribue à Démocrite :* « Tout ce qui existe dans l'univers est le fruit du hasard et de la nécessité. »

(2) Dans la nature, l'eau se trouve sous trois états : liquide, solide et gazeux, identifiés par le cycle de l'eau.
En savoir + : L'eau pour tous – Le défi de l'hydrodiplomatie - *Entretien avec Loïc Fauchon, président honoraire du Conseil mondial de l'eau,* Lettre d'information de l'Institut océanographique Paul Ricard *n° 13, 2014, p. 44.*

(3) Dans les eaux très froides vivent des espèces dites psychrophiles, c'est-à-dire qu'elles ont la capacité de vivre dans des eaux froides comme les mers polaires ou les abysses (90% du volume de l'Océan n'excède pas les 5 °C).

Éclairage

REPRODUCTION
ASEXUÉE OU SEXUÉE ?

L'apparition de la reproduction est un élément clé dans l'évolution de la vie et de la biodiversité. Elle est d'abord asexuée et s'effectue par division cellulaire (mitose*) chez les organismes procaryotes* comme les bactéries et chez les organismes eucaryotes* unicellulaires tels que les protozoaires.

Puis la reproduction devient sexuée chez les organismes eucaryotes* pluricellulaires comme l'oursin. Elle implique une fécondation entre deux gamètes provenant de sexe opposé pour transmettre le patrimoine génétique à la génération suivante.

Cependant, la recombinaison génétique n'est pas forcément sexuée, il existe chez les êtres unicellulaires (bactéries et protistes) la possibilité d'un transfert latéral ou horizontal de gènes, c'est-à-dire un mouvement de gènes entre espèces différentes. Ce qui explique la rapidité à laquelle une bactérie évolue en devenant résistante à des antibiotiques. Ce transfert horizontal de gènes semble également avoir eu lieu et continue à se produire chez les organismes pluricellulaires.

Asexuée (reproduction)
Capacité des organismes vivants à se multiplier seuls : sans partenaire et sans intervention de cellules reproductrices. Il y a donc reproduction à l'identique. Il s'agit en fait d'un clonage. Il existe aussi une forme intermédiaire de reproduction asexuée : la parthénogenèse, c'est-à-dire le développement d'un nouvel individu à partir d'un ovule non fécondé par un mâle.

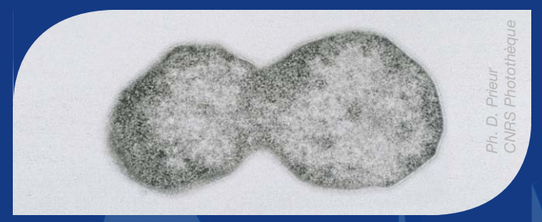
Mitose
Division cellulaire qui assure la naissance de cellules identiques à la cellule mère lors de la multiplication asexuée. L'autre type de division cellulaire dans le monde vivant est la méiose.*

Méiose
Double division de la cellule aboutissant à la réduction de moitié du nombre de chromosomes et qui se produit au moment de la formation des cellules reproductrices, ou gamètes.

Procaryotes
Organismes unicellulaires sans noyau comportant un seul chromosome (bactérie) et aucun organite membrané intracellulaire.

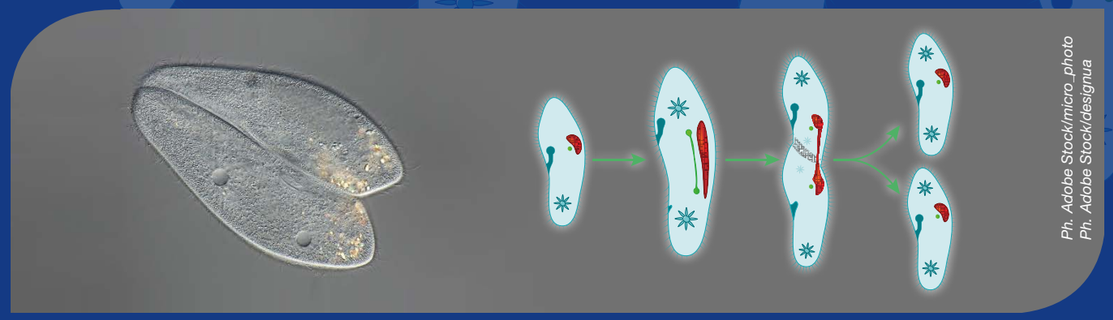
Eucaryotes
Tous les organismes, unicellulaires ou multicellulaires, dont les cellules se caractérisent par la présence d'un noyau et d'organites spécialisés, tels que les mitochondries participant à la respiration cellulaire.

1/ REPRODUCTION ASEXUÉE CHEZ UN ORGANISME PROCARYOTE*
L'exemple d'une bactérie


Ph. D. Prieur CNRS Photothèque

Pyrococcus abyssi *en cours de division cellulaire (mitose*) – Cette bactérie a été isolée d'une source hydrothermal du bassin nord des Fidji, à 2000 mètres de profondeur. Elle vit sans oxygène et métabolise le soufre. Sa température optimale de croissance est de 96°C (vue en microscopie électronique : taille 0,8-2 micromètres).*

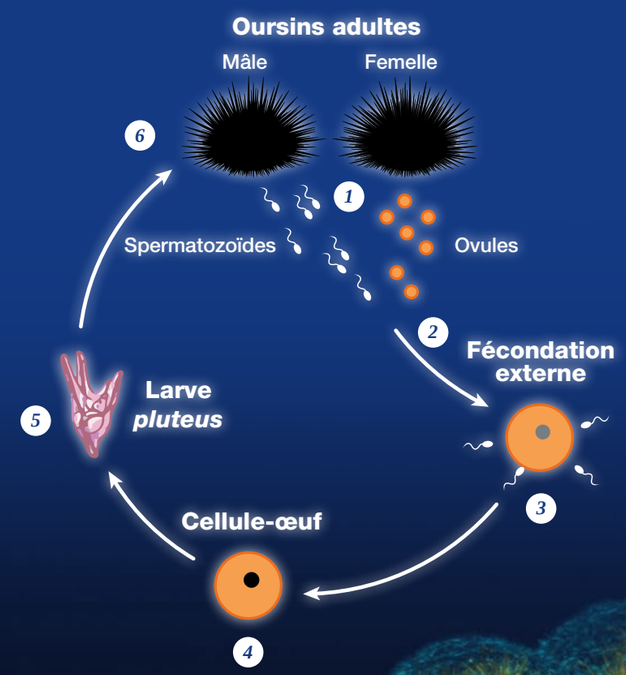
2/ REPRODUCTION ASEXUÉE CHEZ UN ORGANISME EUCARYOTE* UNICELLULAIRE
L'exemple d'un protozoaire


Ph. Adobe Stock/micro_photo
Ph. Adobe Stock/designua

Chez les organismes unicellulaires, la multiplication se fait la plupart du temps par une division binaire, comme ici chez la Paramécie, Paramecium caudatum, *qui possède deux noyaux. Le processus de la mitose* est représenté sur le schéma ci-dessus.*

// DOSSIER ➔ *Biodiversité, vers une nouvelle harmonie ? / Entretien avec Gilles Boeuf*

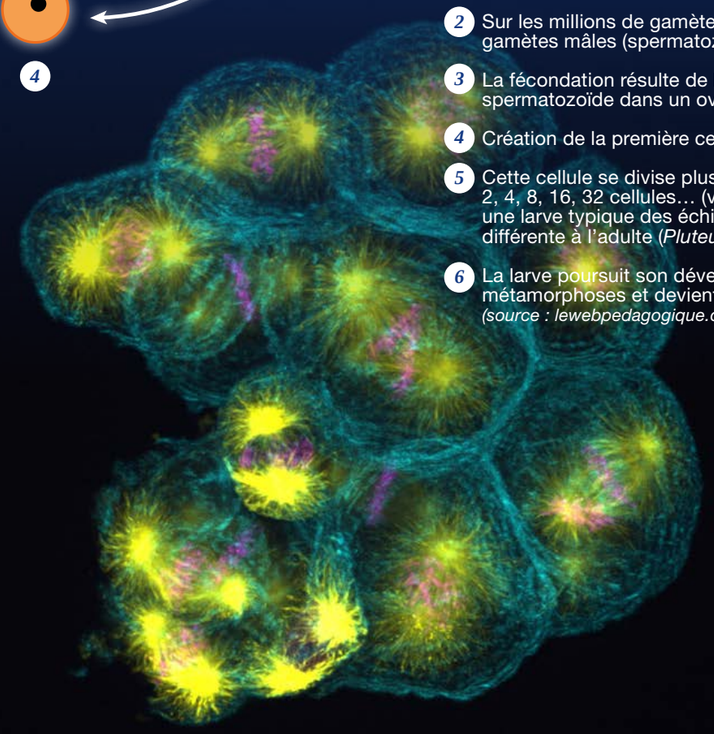
3/ REPRODUCTION SEXUÉE CHEZ UN ORGANISME EUCARYOTE* PLURICELLULAIRE
L'exemple d'un oursin



Sexuée (reproduction)
La reproduction sexuée (animale et végétale) comporte toujours l'union d'une cellule reproductrice mâle et d'une cellule reproductrice femelle. Cette union est la fécondation. Elle aboutit à la formation d'une cellule-œuf, première cellule d'un nouvel individu.
Les descendants auront la moitié de leur patrimoine génétique qui proviendra de leur père et l'autre moitié de leur mère. Ce qui permet le brassage génétique et à la descendance d'acquérir de nouveaux caractères.

Chromosome
Structure constituée d'ADN et de protéines. Dans les cellules eucaryotes, les chromosomes se trouvent dans le noyau et leur nombre varie en fonction des espèces. Une cellule humaine contient 23 paires de chromosomes, dont 22 sont communes aux deux sexes. Les deux paires restantes sont les chromosomes sexuels : XX pour la femme et XY pour l'homme.

1. Les oursins expulsent leurs cellules reproductrices dans la mer.
2. Sur les millions de gamètes femelles (ovules) et de gamètes mâles (spermatozoïdes), 99% disparaîtront.
3. La fécondation résulte de la pénétration d'un unique spermatozoïde dans un ovule.
4. Création de la première cellule du nouvel individu (œuf).
5. Cette cellule se divise plusieurs fois par dédoublement : 2, 4, 8, 16, 32 cellules… (voir photo) pour donner une larve typique des échinodermes de forme différente à l'adulte (*Pluteus*).
6. La larve poursuit son développement, elle subit des métamorphoses et devient un adulte mâle ou femelle *(source : lewebpedagogique.com).*


Ph. J. Dumont/B. Lacroix/CNRS Photothèque

Embryon d'oursin, Paracentrotus lividus, *au stade 32 de la division cellulaire. Le contour en bleu délimite chaque cellule.*
Les couleurs jaune et rouge indiquent l'aire d'alignement et de séparation des chromosomes (image réalisée par immunofluorescence).*

>>

➔ CERTAINS SPÉCIALISTES AVANCENT QUE LA VIE SERAIT APPARUE DANS DES SOURCES HYDROTHERMALES. QUELLE EST VOTRE OPINION SUR CETTE THÉORIE ?

Plutôt que d'imaginer au départ une vie hyper brûlante, je pencherais vers l'hypothèse d'une vie qui apparaît dans des lagunes pas très profondes, au bord de l'Océan, sur le rivage [4]. Il fallait, en fait, que soit réuni un mélange d'apports terrestres et marins.

L'intérêt des milieux côtiers est de présenter une eau pas trop salée, puisqu'elle est souvent mélangée avec de l'eau douce, ce qui est important d'un point de vue cellulaire à cause de la pression osmotique*. Cette eau plus ou moins salée à l'extérieur doit s'équilibrer et échanger avec l'intérieur de la cellule.

On pense aussi que la vie a emprunté le chemin des grands fonds océaniques et de ses sources hydrothermales. Dans quel ordre est-ce survenu ? D'abord sur les rivages puis dans les abysses, ou l'inverse ? Aujourd'hui, la question de savoir d'où provient la vie n'est pas du tout tranchée [5].

➔ EN TOUT ÉTAT DE CAUSE, L'OCÉAN A ÉTÉ LE SIÈGE DE L'APPARITION DE LA VIE. QUE S'EST-IL RÉELLEMENT PASSÉ ?

À l'origine, on passe, d'une cellule sans noyau, une bactérie par exemple – l'ADN* est à l'intérieur d'un seul chromosome* présent dans le cytoplasme* –, à une cellule beaucoup plus compliquée, plus grande, et pourvue d'un noyau regroupant les chromosomes qui contiennent l'ADN*.

> ***Pression osmotique***
> *Force qui est déterminée par une différence de concentration entre deux solutions liquides séparées par une membrane semi-perméable. Ainsi, une concentration en sel extérieure différente de l'intérieur d'une cellule induit un courant d'eau entre les deux compartiments. Par exemple, un globule rouge du sang en condition isotonique, explosera dans l'eau douce et, à l'inverse, perdra de son volume dans l'eau de mer.*

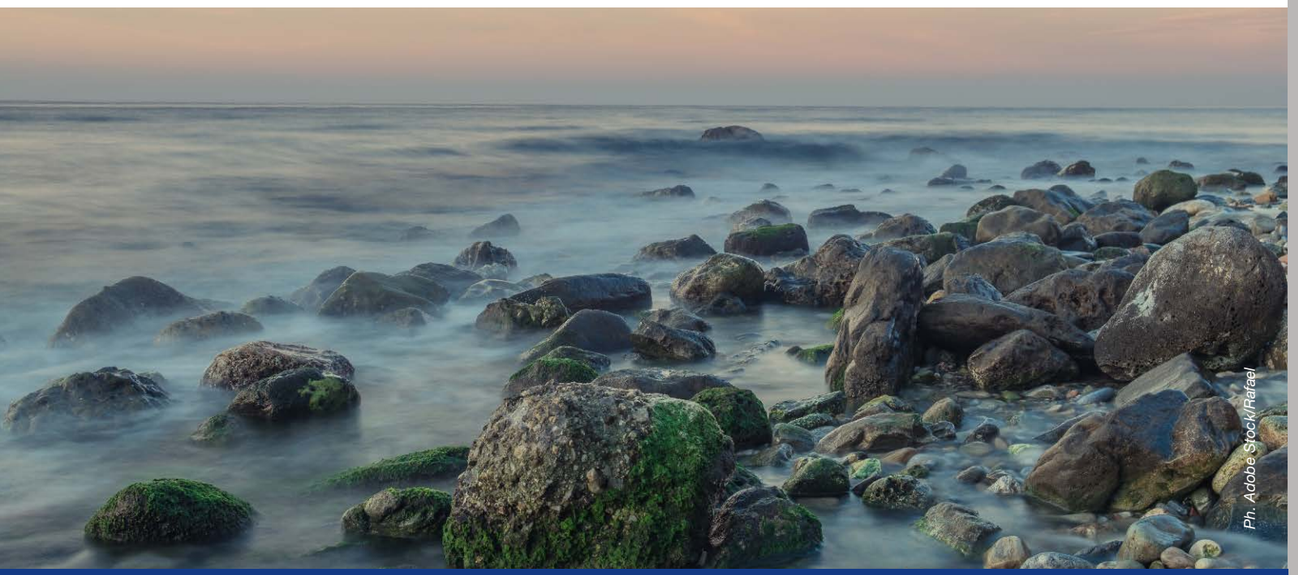
> ***Cytoplasme***
> *Partie interne de la cellule vivante. Sa fraction liquide ou semi-liquide (le cytosol ou hyaloplasme) est composée à 85% d'eau et de protéines. Chez les eucaryotes, elle correspond à la région comprise entre la membrane plasmique et le noyau, siège des chromosomes, et renferme différents organites membranés indispensables aux fonctionnement de la cellule. Chez les procaryotes (bactéries) le cytoplasme est diffus : pas de noyau, pas d'organites membranés, seul un chromosome circulaire.*

Donc, il y a une première évolution, de la cellule simple sans noyau à la cellule avec noyau qu'on appelle protiste. C'est le cas, par exemple, des microalgues et des levures. Le troisième stade se caractérise par un regroupement de cellules à noyau pour constituer un tissu, un foie, un rein, un cerveau, et au final un organisme.

>>

(4) Le 1er février 1871, dans une lettre adressée à Joseph Dalton Hooker, explorateur et botaniste britannique, qui a soutenu ses théories sur l'évolution, Darwin suggère que « l'étincelle de vie d'origine peut avoir commencé dans une petite mare chaude où étaient présents toutes sortes de produits de base, ammoniac et sels phosphoriques, la lumière, la chaleur, l'électricité…, et c'est là qu'un composé protéique s'est formé chimiquement, prêt à subir des changements encore plus complexes. »

(5) En savoir + : https://sagascience.com/origines/



L'environnement marin des rivages a certainement joué un rôle dans l'origine de la vie.

Éclairage

LA LENTE ÉVOLUTION DE LA VIE

L'histoire de l'évolution de la vie couvre plusieurs milliards d'années. À l'origine, elle est marquée par trois grandes étapes innovantes liées à la reproduction des premiers organismes. D'autres évènements fortuits comme les mutations, la sélection naturelle rattachée aux contraintes du milieu,… ont progressivement orienté la spéciation* avec ses divergences et ses convergences de forme.

Ce long cheminement a été souvent compromis par des évènements perturbateurs (cataclysmes) liés à l'évolution de la planète elle-même et à sa position spatiale.

L'évènement le plus marquant de l'histoire de la vie sur la Terre correspond à l'apparition soudaine d'animaux dans les archives fossiles, à la fin de l'ère précambrienne, environ 600 à 555 millions d'années en arrière. Les fossiles de la faune d'Ediacara (Australie) et surtout des Schistes de Burgess (Canada) témoignent de la richesse des espèces dont certaines formes insolites se sont rapidement éteintes.

Ce phénomène remarquable n'en dure pas moins plusieurs millions d'années et se termine vers 505 millions d'années. Au cours de ce foisonnement évolutif, la symétrie bilatérale apparaît chez les animaux. Cet élément important définit le sens du mouvement et favorise la formation d'un système nerveux centralisé. C'est ainsi que se profile l'apparition de la plupart des ancêtres des grands embranchements actuels, entraînant un changement radical de l'aspect de la biosphère.

La conquête des continents survient vers 500 à 359 millions d'années. Cette période correspond à la sortie des eaux des premiers tétrapodes, vertébrés qui descendent des sarcoptérygiens (poissons). Bien d'autres espèces, animales et végétales, prennent le même chemin et colonisent le milieu aérien.

> ***Spéciation***
> *Processus évolutif par lequel de nouvelles espèces vivantes se forment à partir d'ancêtres communs.*

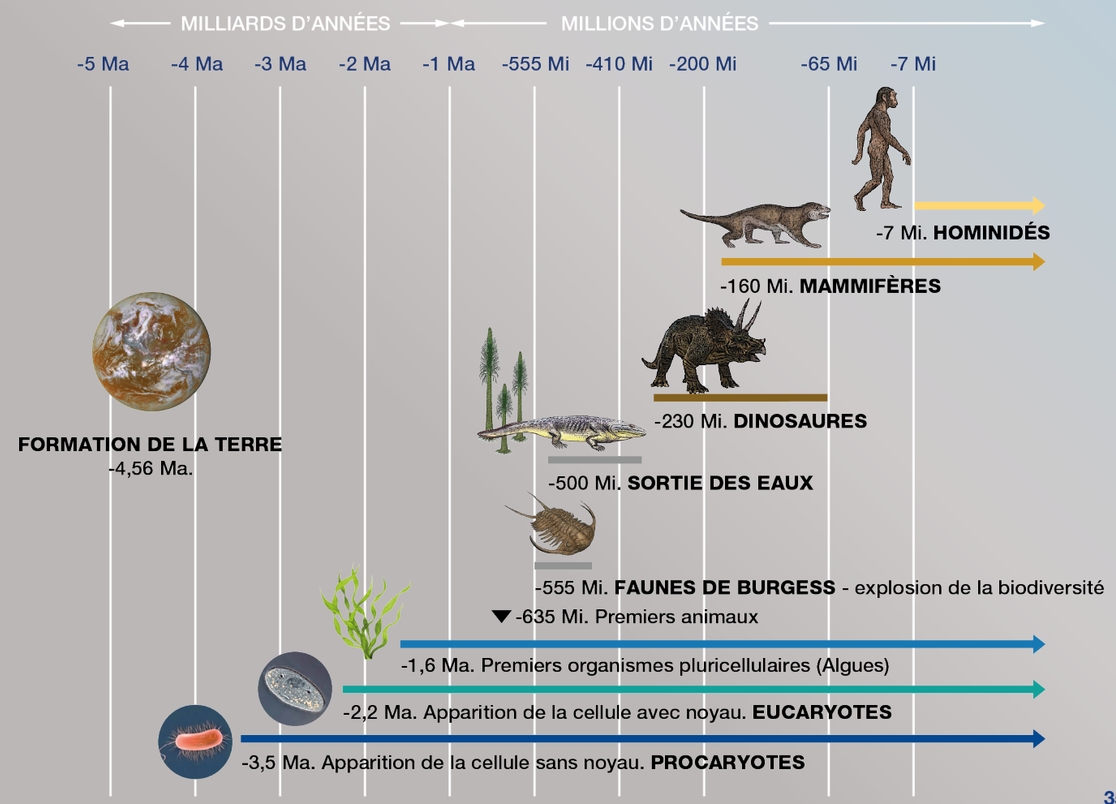
Il y a 252 millions d'années, une extinction massive dont la nature exacte fait encore débat, favorise l'apparition ultra-rapide des dinosaures qui disparaîtront vers 65 millions d'années à la suite de l'impact d'une météorite sur la Terre.

Dans l'histoire des mammifères, une incertitude demeure, celle de l'émergence du premier maillon de ce groupe que l'on situe entre 220 et 180 millions d'années. Conjointement aux dinosaures, les mammifères se diversifient et se répandent largement au milieu du Jurassique, il y a 165 millions d'années. Sans que l'on en connaisse réellement les raisons, ils survivront aux dinosaures pour constituer trois grandes familles.

Vers 7 millions d'années, les premiers Hominidés apparaissent et donneront la lignée conduisant à l'*Homo sapiens*, l'homme. Selon le paléontologue américain Stephen Jay Gould : *« Il nous faut regarder l'évolution comme un ensemble d'évènements à la fois parfaitement logique et susceptible d'être rigoureusement expliqué en rétrospective, mais absolument impossible à prédire et non reproductible »*.

LES GRANDES ÉTAPES DE L'ÉVOLUTION DU VIVANT

Schéma inspiré de : *« La Terre et la Vie - Chronologie »*, *hominidés.com*, Données : G. Boeuf, A. Riva.



>>

➔ CETTE ÉVOLUTION DU VIVANT AU COURS DU TEMPS EST À L'ORIGINE D'UNE BIODIVERSITÉ EXUBÉRANTE DES ESPÈCES MARINES. QU'EST-CE QUI A PRODUIT CETTE EXPLOSION DE VIE ? Y A-T-IL EU DES ÉLÉMENTS DÉTERMINANTS ?

Absolument.
Au départ, le vivant passe d'une cellule sans noyau à une cellule à noyau, et ce qui déclenche la diversité biologique provient d'accidents au moment de la fécondation. Des événements, des rétentions et réactions diverses vont faire que de nouvelles formes apparaissent. Il faudra vraiment attendre l'apparition de la sexualité pour avoir une prolifération du vivant tout à fait extraordinaire sur notre planète.

Dès sa naissance, on peut dire qu'une espèce est déjà plurielle. La première forme de vie de la planète cohabitait déjà avec des organites* d'origine virale. De fait, dès le début du processus évolutif, il y a toujours eu des associations, des symbioses… Et plus le temps passe, plus le nombre d'espèces va augmenter dans l'eau et hors de l'eau. On pense que le pic du plus grand nombre d'espèces sur la Terre a été atteint, il y a environ 200 ans. Depuis cette époque, les dégradations environnementales causées par l'activité humaine n'ont pas cessé de s'amplifier portant de graves atteintes à l'intégrité de la biodiversité.

➔ … DONC, LA SEXUALITÉ EST UN ÉLÉMENT DÉTERMINANT DANS L'ÉVOLUTION DU VIVANT.

Complètement.
Qu'est-ce qu'apporte la sexualité, et surtout le mâle ? C'est une vraie question. Dans certains groupes d'animaux comme les grenouilles et les poissons, il n'y a que des « filles » et aucun « garçon ».

Le sexe mâle n'apparaît alors que si les conditions environnementales changent : il fait trop chaud, trop froid ; le milieu est trop salé, pas assez salé ; l'acidité est trop grande… Dans tous les cas, la sexualité se révèle pour offrir une plus grande possibilité de variations, d'adaptations pour répondre aux changements externes. La sexualité permet de maintenir un maximum de polymorphisme génétique* et, en fait, la clé de la biodiversité, elle est là.

La sexualité est géniale, on naît « garçon » ou « fille », issus de géniteurs mais sans être leur copie conforme : l'idéal pour s'adapter beaucoup mieux à l'environnement. Bien sûr, la sexualité favorise une plus grande variabilité génétique, mais finalement quand on creuse la question, l'une des meilleures hypothèses pour que la sexualité se soit maintenue, c'est que les mâles avaient un rôle antiparasitaire. Voilà à quoi ils servent !

Organites
Structures différenciées que l'on observe dans les cellules eucaryotes avec des fonctions bien précises. Ils baignent dans le cytoplasme et travaillent en coopération.

Polymorphisme génétique
C'est le fait qu'une espèce présente des individus différents avec des caractères phénotypiques différents au sein d'une même population. Le polymorphisme concerne toutes les espèces. Ce sont des variations liées aux mutations génétiques et aux différentes adaptations. Cela correspond par exemple aux mimétismes de formes des papillons.

> ***« Les bons gènes, de la chance, et cela marche… »***

Imaginez qu'un parasite ait trouvé un moyen pour contourner les défenses de la cellule sans qu'elle puisse un jour s'en débarrasser. Avec la sexualité, le brassage génétique va faciliter à terme l'élimination de ce parasite.

➔ PEUT-ON DIRE QUE L'ÉVOLUTION DU VIVANT N'A PAS ÉTÉ UN LONG CHEMIN TRANQUILLE ? Y A-T-IL EU DES INNOVATIONS ET DES RATÉS ? UNE GRANDE PART DE HASARD ?

Sans arrêt, comme le disait notre prix Nobel, Jacques Monod. Aujourd'hui, quand on observe le vivant, on voit déjà celui qui transmettra ses gènes. Contrairement à l'idée reçue, ce n'est pas le plus fort mais le plus malin. C'est lui qui gagne tout le temps et qui va posséder les femelles. Et, s'il est vrai que les mâles entrent en compétition pour l'accès aux femelles, finalement, ce sont elles qui choisissent. Dans l'évolution du vivant, ce n'est pas la loi du plus fort qui va jouer, je dirais plutôt que ce sont les bons gènes et de la chance.

Et comme on ne change pas une équipe qui gagne, le vivant passe par de longues périodes de stabilité. En revanche, le jour où se produit un puissant épisode volcanique, quand la température change, lorsque les précipitations sont intenses ou le milieu est plus sec, plus chaud, plus salé, plus acide, il faut que la vie arrive à surmonter ces difficultés qu'elle n'a jamais rencontrées jusque-là. Je le répète : *« Les bons gènes, de la chance, et cela marche… »*

➔ DANS CE CONTEXTE, COMMENT SITUER LA THÉORIE DE L'ÉVOLUTION ET DE LA SÉLECTION NATURELLE DE DARWIN ?

Ce que je viens de dire est en adéquation avec la théorie de Darwin [(6)]. Et quand les scientifiques de l'Expédition *Tara* ont observé les relations entre les protistes du plancton, ils se sont rendus compte, en fait, qu'il y avait infiniment plus de symbiose, de coopération, d'entraide, de mutualisme, de commensalisme que de compétition entre eux. [voir en page 46 : *Plancton océanique – Des découvertes fondamentales qui vont éclairer le monde et l'avenir du climat.* Entretien avec Colomban de Vargas].

Certes, si on les embête un peu trop, certaines espèces libèrent un poison si violent qu'il tue leurs agresseurs mais c'est rare. Nous constatons plus généralement un système de symbiose entre les organismes depuis l'origine de la vie : même la cellule initiale, était quelque part déjà parasitée par autre « chose » qui existait avant elle.

C'est intéressant car, aujourd'hui, nous savons que dans le corps humain, un dialogue permanent s'instaure entre les différentes cellules qui le composent : les neurones et les cellules gliales* du système nerveux, les cellules musculaires, les globules rouges et les bactéries « hébergées ». L'être humain renferme en lui et sur lui autant de bactéries que de cellules qui lui sont nécessaires. Et si le dialogue est interrompu, c'est le drame avec l'apparition de pathologies comme l'autisme, la maladie d'Alzheimer, le diabète de type 2, l'obésité… C'est pourquoi il faut ramener l'humain à un plus grand respect pour le vivant, car plus on avance dans nos recherches, plus on se rend compte que l'ensemble du vivant est constitué de relations interdépendantes. Mais on ignore encore la plupart de ces interactions étant donné que l'on ne connaît même pas toutes les espèces vivantes.

Gliales (cellules)
Le système nerveux est formé de deux types de cellules : les neurones et les cellules gliales. Ces dernières forment l'environnement des neurones. Elles produisent la myéline et jouent un rôle de soutien et de protection du tissu nerveux en apportant les nutriments et l'oxygène. Elles éliminent aussi les cellules mortes et combattent les organismes pathogènes.

>>

(6) Dans sa théorie, Charles Darwin précise que l'évolution du vivant se fait par sélection naturelle, c'est-à-dire que les organismes les mieux adaptés à leur environnement, grâce à de nouvelles mutations, survivent et transmettent leurs gènes à la génération suivante. Il appelle « sélection naturelle » cette sélection d'individus les mieux adaptés et n'utilise jamais le terme « évolution ». La théorie du célèbre naturaliste englobe à la fois l'idée de compétition et de solidarité. Il rajoute par la suite une « sélection sexuelle », résultat d'une lutte pour la vie entre mâles pour la possession des femelles (source : lejournal.cnrs.com).


Ph. Adobe Stock/Alexis

La symbiose établie par le corail avec des algues microscopiques, les zooxanthelles, est un échange gagnant-gagnant : « hébergement » contre apport de nourriture.


Ph. Adobe Stock/VisionDive

La murène léopard ou murène nid d'abeilles, Gymnothorax favagineus, *se rencontre en mer Rouge, dans l'océan Indien et dans le Pacifique tropical Ouest. Ce poisson vit en association avec des petites crevettes ou des labres qui profitent de la protection de la murène et de ses restes alimentaires. En contrepartie, les hôtes assurent le nettoyage et le déparasitage. Cette forme d'association existe aussi chez l'espèce méditerranéenne,* Muraena helena.

Éclairage

DIVERSIFICATION DU VIVANT

Les populations se modifient au cours du temps, sous l'effet :

…de la sélection naturelle
(théorie de Darwin, milieu du XIXe siècle)

Sous l'effet de la pression exercée par l'environnement, certains individus se reproduisent plus que d'autres.

… de la dérive génétique
(théorie de Motoo Kimura, 1968)

Lors de la reproduction sexuée, sous l'effet du hasard des individus qui se reproduisent et des gamètes utilisés.

Dans les deux cas, on observe une évolution des caractères phénotypiques* de la population au cours du temps. Ces modifications temporelles des populations constituent l'**évolution biologique.**

➔ QUEL EST L'ÉTAT DES CONNAISSANCES SUR LES ÉCOSYSTÈMES ET LES ESPÈCES OCÉANIQUES ? A-T-ON ÉVALUÉ LE NOMBRE D'ESPÈCES ?

La diversité spécifique connue dans l'Océan ne dépasse pas 13% de l'ensemble des espèces vivantes actuellement décrites, soit moins de 300 000 sur plus de deux millions, au total, sur la planète.

La raison en est très simple : les espèces marines vivent dans un espace continu qui change infiniment moins que le milieu terrestre. L'Océan est stable depuis 100 millions d'années.

Par contre, sur Terre, il existe beaucoup plus de barrières et d'isolats* – une vallée, une rivière, des roches différentes –, qui sont favorables à la spéciation, ce processus évolutif par lequel de nouvelles espèces vivantes apparaissent. Un tel morcellement de l'espace entraîne des différences importantes en matière de diversité spécifique : les niches écologiques marines du large n'atteignent pas la richesse de leurs homologues terrestres.

> *“La biodiversité, c'est la fraction vivante de la nature qui appartient à la Terre”*

➔ DANS QUELS SECTEURS LES ESPÈCES SONT-ELLES ENCORE MÉCONNUES ?

Partout. Et en particulier, dans le profond, évidemment.

On se rend compte que le littoral est très riche – et l'on revient à ces questions d'origine de la vie –, parce que le rivage se féconde, s'enrichit en permanence par ce qui provient de la terre, les apports terrigènes. Finalement, c'est là que le système se développe le plus, il y a infiniment plus d'espèces en bordure des continents que dans le grand large océanique. Regardez une mappemonde : on dit toujours que l'Océan occupe 71% de la superficie de la Terre, c'est vrai, mais il faut aussi considérer l'Océan en volume : 99% de son volume est offert à la vie, avec d'énormes réservoirs où il n'y a pas grand-chose et d'autres, extrêmement riches.

Aujourd'hui sur la Terre, tout compris, la grande forêt tropicale est le réservoir d'espèces le plus important avec trois grands bassins : celui du Congo en Afrique ; en Asie, les deux grandes îles que sont la Papouasie-Nouvelle Guinée et Bornéo, et l'Amazonie, en Amérique.

Dans l'Océan, le récif corallien est le plus riche. Avec moins de 1% en surface, il abrite plus du tiers des espèces connues aujourd'hui.

Phénotypiques (caractères)
Ensemble des caractères apparents d'un individu.

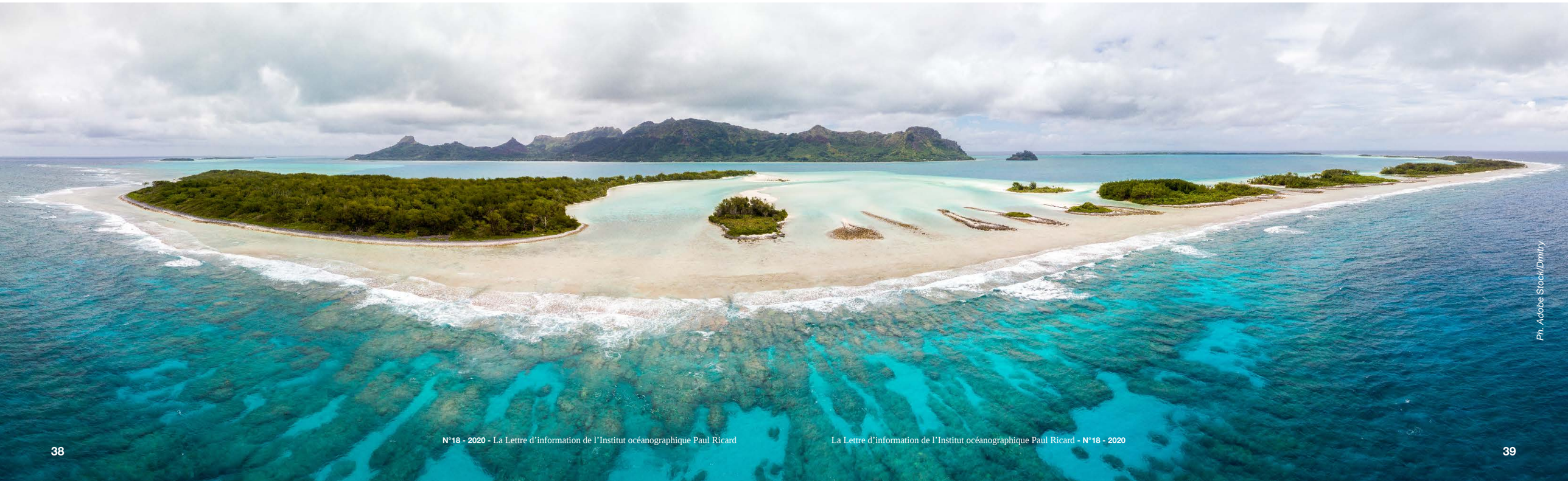
Isolat
Petit écosystème complètement isolé qui abrite une biocénose n'ayant aucun échange génétique avec le reste du monde et menacée par le confinement : par exemple une île, un lac, un massif montagneux, une oasis…

➔ À CE STADE DE NOTRE ENTRETIEN, COMMENT PEUT-ON DÉFINIR LA BIODIVERSITÉ ?

J'ai formulé une idée très simple dans ma leçon inaugurale au Collège de France : la biodiversité, c'est tout simplement la fraction vivante de la nature qui appartient à la Terre. Elle naît le jour de l'apparition de la première cellule dans l'Océan et, après, son histoire est celle de la diversification : des bactéries vers les protistes, les champignons, les plantes et les animaux en mer et sur la Terre. Donc, la biodiversité est aussi l'ensemble de toutes les relations que les êtres vivants ont établies entre eux et avec l'environnement.

>>

L'île de Raivavae et son remarquable récif corallien, dans l'archipel des Australes (Polynésie française).

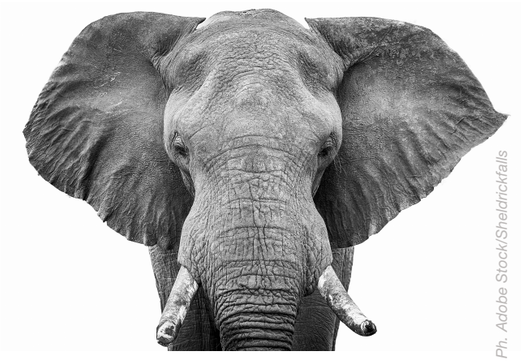


Ph. Adobe Stock/Dmitry

2/ Effondrement de la biodiversité marine, les facteurs et leurs effets


Ph. Adobe Stock/Amit

> *“Nous avons tué la moitié des girafes, des éléphants, des lions, des guépard et des tigres”*


Ph. Adobe Stock/Sheldrickfalls


Ph. Adobe Stock/AB Photography

➔ SELON LA PLATEFORME INTERGOUVERNEMENTALE SCIENTIFIQUE ET POLITIQUE SUR LA BIODIVERSITÉ ET LES SERVICES ÉCOSYSTÉMIQUES (IPBES), UN MILLION D'ESPÈCES ANIMALES ET VÉGÉTALES RISQUENT DE DISPARAÎTRE DANS LES PROCHAINES DÉCENNIES DE LA SURFACE DE LA TERRE ET DU FOND DES OCÉANS. APPROUVEZ-VOUS CE CHIFFRE-CHOC ?

Non, je ne l'aurais jamais formulé comme cela. D'abord, parce que l'on ne connaît pas le nombre exact d'espèces. J'ai parlé de plus de deux millions d'espèces connues. Je pense qu'il y en a 10 fois plus, ce qui en ferait 20 millions sur la Terre : Océan et continents compris.

Où sont passés les 18 millions qui manquent ? Et depuis 20 ans, rien ne change : chaque année, entre 16 000 et 18 000 espèces nouvelles sont décrites. Elles ne sont pas apparues, elles n'étaient tout simplement pas encore connues. Au rythme actuel des descriptions, il faudra 1000 ans pour établir un catalogue complet des espèces existantes !

En revanche, et là où je suis en accord avec l'IPBES, c'est qu'au rythme actuel de la disparition d'espèces, nous allons en perdre la moitié avant la fin de ce siècle.

> *“Globalement, l'humain crée aujourd'hui des contraintes qui amènent le vivant à disparaître”*

Une énorme partie de la biodiversité risque effectivement de disparaître à une échéance assez brève. Concernant les grands animaux, nous avons tué la moitié des girafes, des éléphants, des lions, des guépards et des tigres en 40 ans. Il reste 2% de baleines arctiques et antarctiques, les baleines franches. Pour les stocks de poissons, la situation est tout aussi préoccupante. Et, bien sûr, nous n'avons aucune idée sur la situation des champignons, des bactéries…

Globalement, l'humain crée aujourd'hui des contraintes qui amènent le vivant à disparaître.

➔ CERTAINS SCIENTIFIQUES PARLENT D'UNE SIXIÈME EXTINCTION DE MASSE DES ESPÈCES MARINES ET CONTINENTALES. QU'EN PENSEZ-VOUS ?

Le mot extinction ne me plaît pas trop parce que si des extinctions d'espèces ont réellement eu lieu dans un passé lointain, aujourd'hui, il s'agit plutôt d'un effondrement du nombre d'individus dans les populations vivantes sauvages et une prolifération des animaux domestiques. Il est scientifiquement démontré que nous n'avons jamais eu autant de chats, de chiens, de poulets, de cochons et de vaches… Selon Franck Courchamp, écologue de l'Université Paris-Sud Orsay : *« Le seul gros animal qu'il restera demain, c'est la vache »*. C'est assez affligeant, tout de même !

Pour revenir à votre question, des collègues géologues – Anthony D. Barnosky et ses collaborateurs –, posaient en effet cette question dans la revue *Nature*, dès mars 2011 : *« Sommes-nous en train de créer les conditions de la sixième grande crise d'extinction ? »*

Le vivant a traversé 60 crises d'extinction des espèces depuis 800 millions d'années, dont cinq ont été répertoriées comme majeures.

La troisième, entre la fin de l'ère primaire et le début de l'ère secondaire, a fait disparaître 95% des espèces marines et 70% des espèces continentales. La dernière, la cinquième, que l'on connaît bien, a vu l'extinction des dinosaures, il y a 65,5 millions d'années.

Pour les géologues, une crise d'extinction est la disparition d'au moins les trois-quarts des espèces dans l'Océan et sur les continents, en un temps relativement bref à l'échelle géologique.

Aujourd'hui, par exemple, il existe 700 espèces d'oursins connues sur notre planète. Seulement deux espèces ont réussi à passer de l'ère primaire à l'ère secondaire. Ce qui veut dire que les 700 espèces qui vivent aujourd'hui sont issues de ces deux espèces survivantes de la crise d'extinction. C'était vraiment limite, limite… Les trilobites, eux, ont définitivement disparu, les coraux tabulés [7], aussi.
Donc, encore une fois, il faut les bons gènes et de la chance… Les oursins sont passés, pas les trilobites.


Ph. DR

Fossile de trilobite – Ces arthropodes marins ont existé durant le Paléozoïque (ère primaire), du Cambrien au Permien. Les derniers ont disparu, il y a 250 millions d'années.

Il est vrai que nous vivons une situation qui rappelle par endroits ce qui est survenu avec les grandes crises d'extinction, mais c'est différent. Aujourd'hui, il s'agit d'un effondrement continu et accéléré de la biodiversité marine qui est causé essentiellement par les impacts de l'activité humaine [voir en page 40 : *Le vivant en péril – Menace accélérée d'extinctions*].

>>

(7) Les coraux tabulés constituent un ordre éteint de coraux solitaires. Abondant de l'Ordovicien au Permien, ce groupe a disparu lors de l'extinction massive du Permien.

Ph. Adobe Stock/roggui

Éclairage

LE VIVANT EN PÉRIL

MENACE ACCÉLÉRÉE D'EXTINCTIONS

La Liste rouge de l'Union internationale pour la conservation de la nature (UICN) dresse l'inventaire mondial de l'état de conservation global des espèces végétales et animales de la planète. La dernière édition (version 2019.3) établit un bilan des espèces menacées d'extinction, par groupes :

- ***41,5%*** **des amphibiens**
- ***14%*** **des oiseaux**
- ***25%*** **des mammifères**
- ***31%*** **des requins et des raies**
- ***33%*** **des coraux constructeurs de récifs**
- **On estime que *40%* de l'écosystème maritime sont fortement altérés**

(sources : uicn.fr et IPBES)

Ph. Adobe Stock/D. Brandelet

Les populations de requins-marteaux, ici une concentration aux Galapagos, ont diminué de 50% au cours de ces dix dernières années.

>>

➔ QUELS SONT LES FACTEURS DE L'EFFONDREMENT ACTUEL DES ESPÈCES MARINES ?

Cet effondrement est lié à la bêtise humaine. Les causes sont diverses et très connues, mais elles sont toutes rattachées à l'activité humaine.

• **Nous détruisons le littoral**, qui est particulièrement riche en espèces de divers groupes.

• **Nous polluons tout, partout,** c'est dramatique : rejet d'eaux usées non traitées, dispersion de pesticides, d'insecticides et de métaux lourds…, plastiques (1) charriés par les fleuves jusqu'à l'Océan…

Regardez le cas du chlordécone, un insecticide qui a été utilisé dans les Antilles françaises entre 1972 et 1993 pour lutter contre le charançon du bananier. Pour gagner quelques centimes sur le prix du kilo de bananes, l'environnement a été empoisonné pour deux siècles. Les « fruits de mer » peuvent être menacés.

• **Nous surexploitons les ressources vivantes :** pêcher c'est très bien, surpêcher c'est stupide, car on tue en permanence *« la poule aux œufs d'or »*.

La situation mondiale est très préoccupante : en 15 ans, on a extirpé de l'Océan entre 50 et 90% de tous les grands individus des poissons pélagiques ! Les trois-quarts des stocks sont pleinement exploités ou surexploités. Le vivant a dû s'adapter : en Méditerranée, en raison d'une surpêche, le merlu se reproduit à deux ans au lieu de quatre. Les juvéniles sont beaucoup plus petits !
En France, le cas du saumon (2) est incroyable : ce poisson était pêché quand il remontait les rivières, juste avant… qu'il ne se reproduise ! Une autre espèce emblématique est en cours d'extinction dans notre pays : l'esturgeon européen (3). Aujourd'hui, il n'en reste même pas une centaine dans la nature, alors que ce poisson était abondant dans la Dordogne et la Garonne. Il a disparu parce qu'il a été trop pêché et que l'on a pollué son environnement. Même sort pour le dauphin d'eau douce (4) du Yang-Tsé-Kiang, en Chine. Selon l'UICN (données de 2017), il est en danger critique d'extinction, voire éteint.

Les raisons principales du déclin fulgurant des populations en 50 ans sont la pollution, une modification de l'habitat du cétacé et une pêche intensive.

• **Nous disséminons de tout, partout** [8]

Un pétrolier géant qui pompe 300 milles tonnes d'eau de mer pour remplir ses ballasts à Rotterdam et qui les rejette à Abou Dabi ou à Oman, bourrés de bactéries, de virus et de microalgues, c'est vraiment un problème dramatique. Autre exemple : en Méditerranée, dans les années 1980, une micro-méduse – le cténophore *Mnemiopsis leidyi* – arrive accidentellement en mer Noire dans les eaux de ballast d'un bateau américain. Manque de chance pour l'environnement immédiat, cet animal s'installe sans ses parasites et sans ses prédateurs. Les populations explosent et, pour se nourrir, les méduses entrent en compétition avec les anchois, dont elles font chuter les stocks. Un déclin drastique de la pêche est enregistré dans la région.

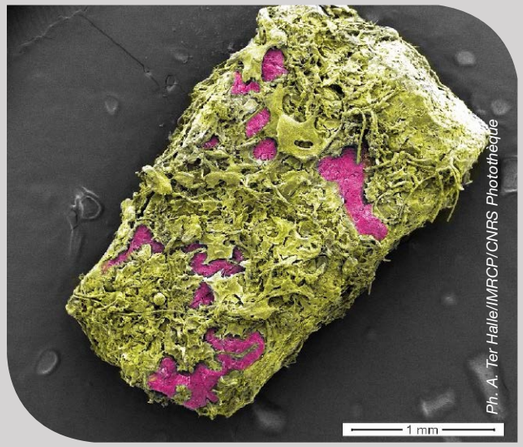
• **Le climat change trop vite**, avec deux réactions immédiates.

Quand la température de l'Océan augmente, le métabolisme de l'être vivant augmente : il respire plus, prend plus d'oxygène, alors qu'il y en a de moins en moins dans l'eau.
Seconde réaction immédiate, il migre pour ne pas être mal à l'aise : dans l'hémisphère Nord, il va vers le nord ; dans l'hémisphère Sud, il se dirige vers le sud.
S'il n'a pas de barrière, le vivant part vers des régions qui lui sont plus favorables. Les lançons (5) quittent la Normandie pour la mer du Nord ; les anchois sortent de Méditerranée et remontent vers le nord. Cela pose problème dans cette mer quasi-fermée. Comment vont réagir les espèces ? Aucune pancarte ne leur indique la sortie. Et d'autant que les espèces entrent beaucoup plus en Méditerranée qu'elles n'en sortent par le canal de Suez. Ne reste que le détroit de Gibraltar pour s'échapper…

Tous ces impacts en peu de temps, convenez que cela fait beaucoup pour le vivant.

>>

(8) Selon Philippe Goulletquer, directeur scientifique adjoint de l'Ifremer 325 cas d'espèces introduites, aussi appelées « non indigènes », *ont été recensés sur les côtes françaises. Elles sont arrivées principalement fixées sur les coques des navires pour les algues et les mollusques ou elles ont été relarguées avec les eaux de ballast pour le phytoplancton, des larves, des bactéries… 60 % des espèces introduites dans le monde transitent par cette voie* (source : Reporterre, 16 novembre 2016).



Ph. A. Ter Halle/IMRCP/CNPS Photothèque

Gyres océaniques

Immenses tourbillons d'eau que l'on trouve dans les océans et qui résultent de la combinaison d'un ensemble de courants marins. Ils sont provoqués par les vents à la surface des océans et la rotation de la Terre (via la force de Coriolis). Ils tournent donc dans le sens des aiguilles d'une montre dans l'hémisphère Nord et dans le sens contraire dans l'hémisphère Sud.
Ces tourbillons (ou vortex) entraînent tous les objets et débris de plastique flottant à la surface de l'eau et favorisent leur accumulation d'année en année.

Anadrome (espèce)

Espèce vivant en mer et se reproduisant en eau douce.

(1) *Débris de plastique collecté dans le gyre océanique* de l'Atlantique Nord, où s'accumulent les déchets plastiques flottants – Cette matière se fragmente en petits morceaux qui sont très colonisés. Les petits radeaux peuvent transporter des espèces potentiellement invasives. Ils parcourent des milliers de kilomètres pendant des années* (Expéditions 7e Continent/2014. Observation en microscopie électronique à balayage, image colorisée – taille : un millimètre).

Ph. Adobe Stock/jamie

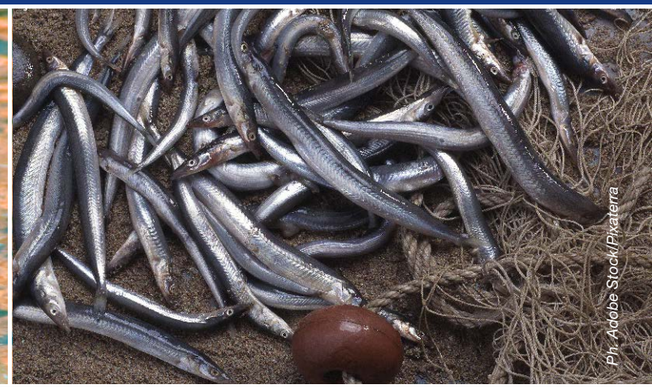
(2) *Saumon atlantique,* Salmo salar *– Protégé en France depuis 1988, il a disparu de la plupart de nos cours d'eau, victime d'une pêche excessive et de la construction de barrages. Grâce à un plan de sauvegarde et de repeuplement, ce saumon sauvage a pu se maintenir dans la Loire et son affluent l'Allier, ainsi que dans d'autres cours d'eau comme l'Adour.*

Ph. Adobe Stock/Vladimir Wrangel

(3) *Esturgeon d'Europe,* Acipenser sturio *– Le plus grand poisson migrateur anadrome* de France a connu une forte régression des populations qui l'a conduit au bord de l'extinction. Aujourd'hui, il fait l'objet d'un plan de sauvetage avec, entre autres, un rempoissonnement à partir d'élevages.*

Ph. Adobe Stock/kanjovit

(4) *Dauphin de Chine,* Lipotes vexillifer *– Surnommé le* Baiji, *c'était l'un des rares cétacés à vivre en eau douce.*



Ph. Adobe Stock/Pixaterra

(5) *Lançon équille,* Ammodytes tobianus. *Ces anguilles de sable se pêchent surtout à l'aide de sennes à mailles très fines ou à l'aide de râteaux. Elles peuvent servir d'appâts pour la pêche aux bars, turbots, maquereaux, congres...*

3/ Les moyens d'enrayer l'effondrement de la biodiversité marine

➔ PEUT-ON ENRAYER L'EFFONDREMENT DU VIVANT ?

Pour répondre à cette question, j'utilise souvent une image. Qu'est-ce que l'on mange ? On ne mange pas de quartz, on ne mange pas de chaussures…, on se nourrit exclusivement de la biodiversité. Et surtout l'humain coopère avec elle.

Le corps humain, c'est autant de bactéries que de cellules humaines. Un arbre concentre plus de biomasse de bactéries ou de micro-organismes que de cellules d'arbre. Donc, nous ne pouvons pas nous passer de la biodiversité. Je le dis à qui veut l'entendre : chaque matin, nous nous réveillons après avoir dormi avec un à deux millions d'acariens dans notre lit. Si nous admettons de faire partie du vivant et ne pas être en marge, cela change tout, parce que si nous l'agressons, nous nous auto-agressons. Nous devons en être conscients.

Si la biodiversité s'effondre, nous n'aurons plus rien à manger et avec qui allons-nous coopérer demain ? Et l'on ira jusqu'à s'exposer à l'émergence de situations qui conditionneront l'apparition de maladies [9].

Il est vrai que nous vivons aujourd'hui un effondrement des espèces, dans un irrespect total de quelque chose qui est pourtant indispensable. L'humain doit admettre qu'il n'est pas à côté de la nature, mais dedans.

> *« Si nous admettons faire partie du vivant et ne pas être en dehors, alors cela change tout »*

➔ LE RECOURS AUX SOLUTIONS FONDÉES SUR LA NATURE PEUT-IL SERVIR AU MIEUX LA PRÉSERVATION ET LA GESTION SOUTENABLE DE LA BIODIVERSITÉ ?

Bien sûr, c'est beaucoup plus intelligent.

Je prends souvent pour exemple la libellule. Elle pèse deux grammes, mais elle vole à 100 kilomètres/heure avec deux watts d'énergie ! Elle encaisse 30 « g » en accélération, presque trois fois la pression subie par un pilote de chasse. En plus, l'insecte voit 300 images par seconde à 360°. Mais comment fait-elle ?

La libellule est pourvue d'énormes yeux, par rapport à sa taille. Comme tous les insectes, ces yeux sont composés, c'est-à-dire qu'ils présentent chacun près de 30 000 facettes, qui cachent en réalité des petits yeux simples, appelés ommatidies (récepteurs sensibles à la lumière). Les yeux composés ont évolué il y a très longtemps. On en trouve sur les premiers arthropodes présents dans les schistes de Burgess (Cambrien) et également sur les trilobites.

Depuis plusieurs centaines de millions d'années, une microalgue du plancton marin, une diatomée, se fabrique à température ambiante une carapace protectrice en verre à partir de la silice dissoute dans l'eau. Dans l'industrie, il faut chauffer le sable siliceux à une température de 1550°C pour obtenir le même résultat.

De petites éponges siliceuses élaborent un béton armé qui est beaucoup plus léger et plus résistant que celui que nous utilisons. L'agencement en peau d'oignon des couches de silice empêche la fissuration. Un tel bio-matériau peut se déformer et reprendre sa forme initiale.

En Méditerranée, les herbiers de Posidonies sont cinquante fois plus performants que la forêt tropicale pour stocker du carbone. C'est super intéressant. On replante des arbres, replantons des Posidonies !

Que l'humain s'inspire du vivant ! Pour moi, la bio-inspiration est l'outil le plus puissant qui soit. Cela signifie qu'il faut chercher dans le vivant des réponses technologiques à nos questions.

Aujourd'hui, cette approche est l'une des plus intéressantes pour faire beaucoup mieux que l'on ne sait faire. Le vivant a eu beaucoup de temps pour expérimenter et il a dû relever tellement de défis avant nous. Il a quatre milliards d'années de recherche et développement. Mais pour en tirer parti, il faut tuer notre arrogance, tuer notre imprévoyance et se dire : *« Comment le vivant aurait-il fait dans ma situation ? »*.

Le vivant innove en permanence. Le vivant ne produit jamais une substance qu'il ne sait pas dégrader. Il fait des poisons horribles comme le venin de cône marin, mais il invente des façons de les éliminer.

Le vivant fait tout avec une énorme économie d'énergie.

Le vivant ne produit jamais un déchet pour lequel il n'a pas d'acheteur, alors que nous avons inventé 150 000 molécules depuis les années 1950. Le vivant est incapable de les recycler et nous non plus. Et tous ces polluants nous empoisonnent, comme les redoutables perturbateurs endocriniens dont on ne sait que faire.

Stoppons une économie stupide et suicidaire qui consiste à faire du profit en détruisant la nature et en la surexploitant. À ce prix-là, on peut encore gagner la bataille du vivant.

> *« Stoppons une économie stupide et suicidaire qui consiste à faire du profit en détruisant la nature et en la surexploitant »*

➔ LE DÉVELOPPEMENT D'AIRES MARINES PROTÉGÉES VA-T-IL DANS LE MÊME SENS DE GESTION SOUTENABLE DE LA BIODIVERSITÉ ?

Oui, c'est une bonne idée [10]. Mais les AMP qui marchent sont celles où des moyens sont injectés pour empêcher les impacts délétères dont on a déjà parlé : la surpêche, et même toute forme de pêche, la pollution, la dissémination d'organismes exogènes…

Les espèces qui évoluent dans ces milieux protégés gardent aussi des capacités à mieux résister au changement climatique, elles migrent moins que d'autres. Mais les réserves marines destinées à protéger une espèce particulière, vont, à terme, la voir disparaître et être remplacée par d'autres manifestations du vivant.

➔ LA RESTAURATION ÉCOLOGIQUE DES MILIEUX NATURELS EST-ELLE AUSSI UNE AUTRE VOIE ?

Cela va dans le même sens.

Ce qui m'intéresse dans la restauration des écosystèmes dégradés, c'est son coût. Il revient toujours beaucoup plus cher que si l'on avait veillé à ne pas détruire l'environnement. Et j'en viens à la résilience des écosystèmes, c'est-à-dire le fait qu'après un traumatisme, une agression, un écosystème revient à un état plus ou moins proche de celui qui était le sien auparavant.

Mais n'oublions jamais une chose : il est impossible de résilier lorsque l'on est mort. Arrêtons de détruire, c'est très important. L'Océan est très puissant en terme de résilience, il faut le préserver.

➔ NOUS LE VOYONS, CERTAINES SOLUTIONS EXISTENT MAIS FACE AU POUVOIR DESTRUCTEUR DE L'HOMME, EST-IL POSSIBLE D'INVERSER LA TENDANCE ?

Oui, j'y crois. Je dis souvent qu'il est trop tard pour être pessimiste, il fallait l'être avant. Résolument, il faut prendre le problème à bras le corps.

Je m'oppose aux collapsologues, qui sont en train de dégoûter mes étudiants. *« Tout est perdu, on ne peut plus rien faire »*, disent-ils. C'est faux ! Mais plus on attend, plus ce sera difficile, plus cela coûtera cher et amènera de la souffrance.

>>

(9) Entre 1940 et 2004, 300 maladies nouvelles sont apparues chez l'homme. Elles sont liées soit à l'effondrement du vivant, soit au changement climatique (source : L'effondrement de la biodiversité a-t-il une incidence médicale ?*, par Bernard Swynghedauw, Espèces n°5, septembre 2012).*

(10) L'idée de protéger la biodiversité dans des espaces dédiés est née au 19e siècle aux Etats- Unis : le premier parc national date de 1872 avec Yellowstone, connu pour sa biodiversité, ses nombreux écosystèmes et ses geysers. En Europe, la Suède a été un pays précurseur en créant 9 parcs nationaux dès 1909. La France a suivi tardivement, avec son premier parc national terrestre, la Vanoise, et le premier parc marin européen, Port-Cros, en 1963.

>>

➔ PENSEZ-VOUS QUE L'ON PEUT ENCORE RÉTABLIR DES HARMONIES TROUBLÉES ?

J'y crois très fort, sinon j'arrêterais mes cours et mes conférences. Les jeunes y croient aussi. Mais pour les rassurer, il faut faire beaucoup plus que de leur demander de couper l'eau du robinet quand ils se lavent les dents. Il faut vraiment aller vers des choses tangibles, aborder des sujets importants, forts et emblématiques.

Depuis quelques années, je pense que la jeunesse actuelle l'a compris avec un aspect qui me plaît énormément : pour elle, l'argent n'est pas le seul intérêt. C'est le bien-être, le bien-vivre, l'échange, l'harmonie que vous avez évoquée. C'est très encourageant.

> *“Il faut retrouver de l'amour”*

Je pense que l'horizon 2040 est vraiment à risques. Alors, aidons les jeunes à mettre le pied à l'étrier, écoutons-les, partageons avec eux. Et demain, le leitmotiv, le bon sens de la vie ne sera pas l'argent, mais le bien-être et le plaisir. Il faut retrouver de l'amour. ■

Entretien avec Christian Frasson-Botton
Février 2020

Photo ci-contre : Aire marine protégée de la baie de Gokova (Turquie) – La gestion communautaire de la pêche artisanale a été distinguée par la Commission Générale des Pêches pour la Méditerranée comme étant la meilleure pratique en matière de pêche artisanale en Méditerranée et en mer Noire.

À LIRE

• *Jamais seul*, Marc-André Selosse, Actes Sud, 2017.

• *L'adaptation au changement climatique*. Sous la direction de A. Euzen, B. Laville et S. Thiébault, CNRS Éditions, 2017.

• Collectif, *L'océan à découvert*, CNRS Éditions, 2017.

• *L'Homme peut-il accepter ses limites ?* Sous la direction de G. Boeuf, B. Swynghedauw et J.- F. Toussaint, Éditions Quae, 2017.

• *Comment la vie a commencé, les trois genèses du vivant*, Alexandre Meinesz, Éditions Belin, Collection Alpha, 2016.

• *Océan, biodiversité et climat*. Fiche pour la Plateforme Océan et climat, ministère de l'Environnement, de l'Énergie et de la Mer, Fondation de France, 2015.

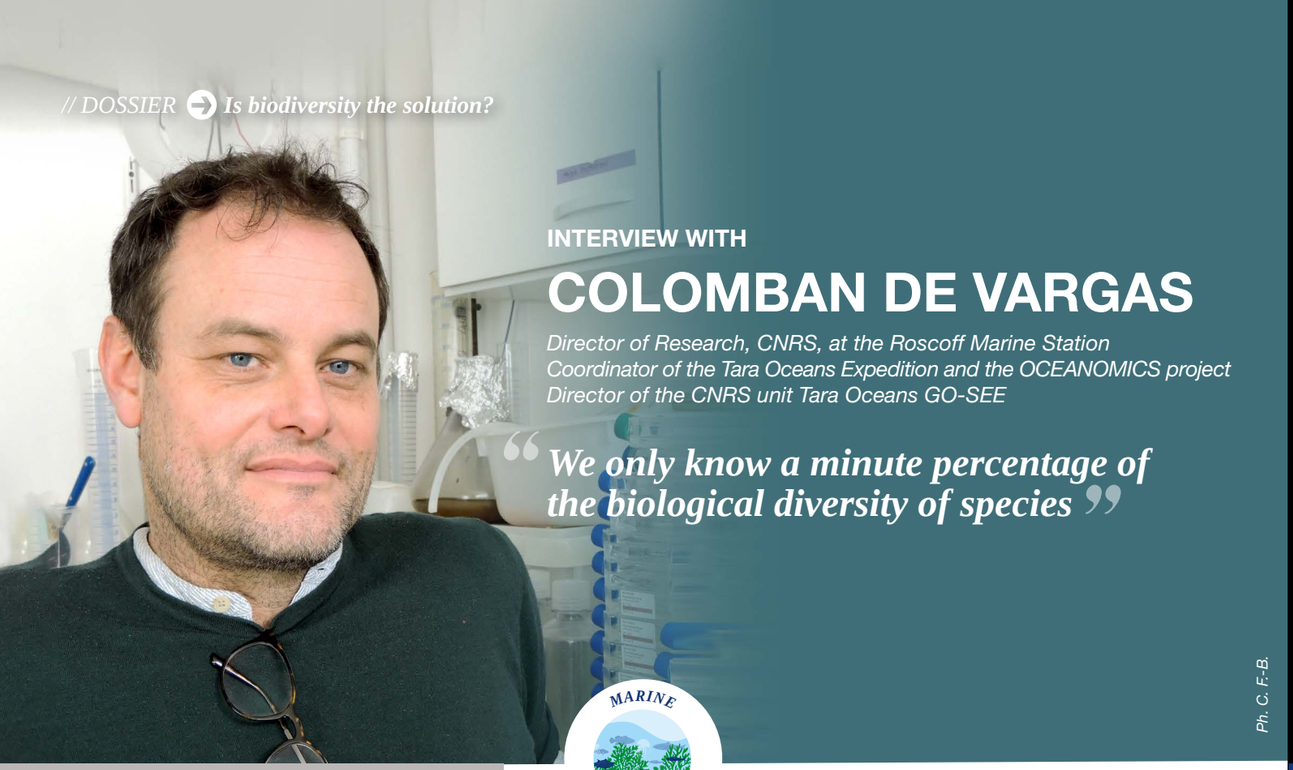
• *La biodiversité, de l'Océan à la cité*, Gilles Boeuf, Fayard, Collège de France, Leçons inaugurales, 2014.

• *Vulnérabilité du système océanique*, Gilles Boeuf, sous la direction de A. Monaco et P. Prouzet, Hermès, ISTE Éditions, Collection Mer et Océan, 2014.

• *Biodiversité en environnement marin*, Philippe Goulletquer, Philippe Gros, Gilles Boeuf, Jacques Weber, Éditions Quae, 2013.

• *La vie est belle, les surprises de l'évolution*, Stephen Jay Gould, Editions du Seuil, Science ouverte, 1991.

Ph. Adobe Stock/anemone



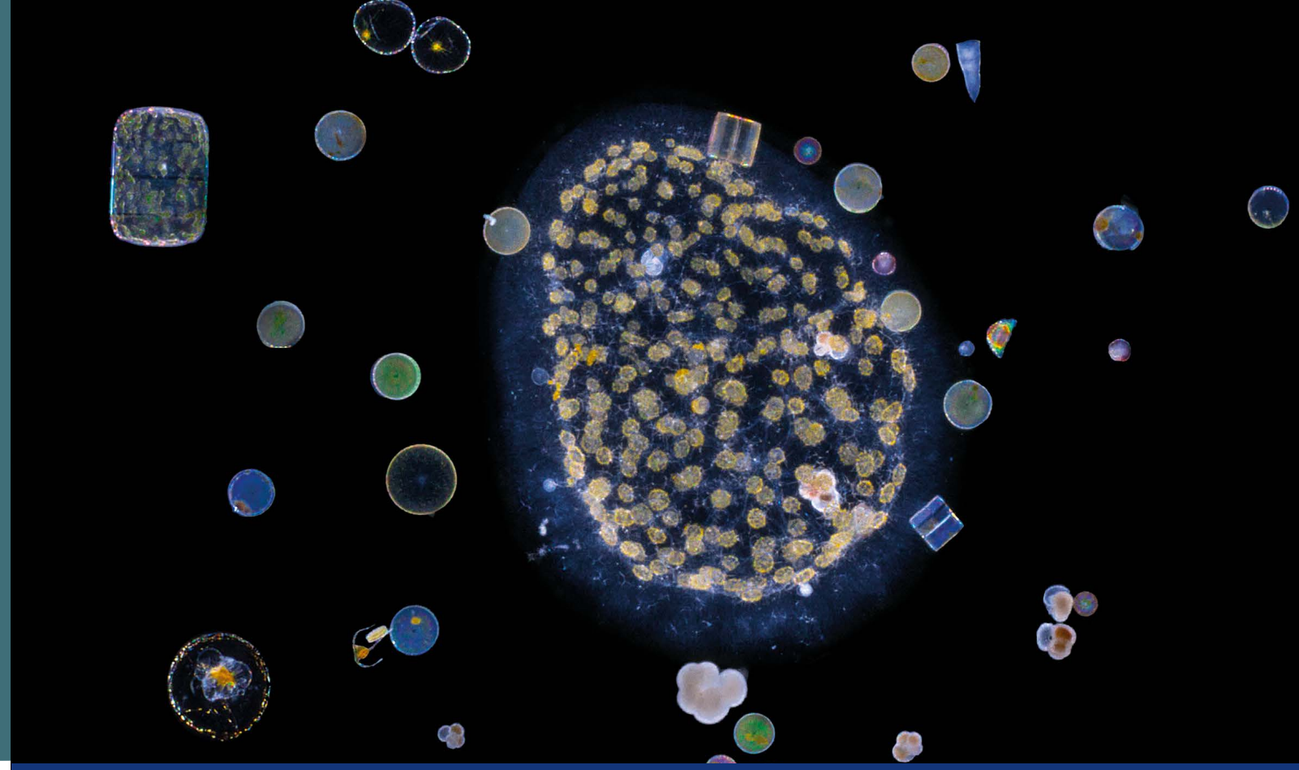
INTERVIEW WITH

COLOMBAN DE VARGAS

Director of Research, CNRS, at the Roscoff Marine Station
Coordinator of the Tara Oceans Expedition and the OCEANOMICS project
Director of the CNRS unit Tara Oceans GO-SEE

"We only know a minute percentage of the biological diversity of species"

Ph. C. F.-B.



A wide spectrum of shapes and colours for these protists in the Atlantic Ocean. Present in all the world's oceans, these complex cells known as eukaryotes are thought to form one of the essential components of the marine plankton and to play a major role in the regulation of the climate mechanism.*

CAREER

1971
Born in Paris.

1995
Master of Science (MSc) research in the Tuamotu islands (French Polynesia).

2000
PhD in molecular evolution and phylogenetics, University of Geneva (Switzerland).

2000-2002
Post-doctoral fellow at Harvard University (USA), studying the genetics of populations and micropalaeontology.

2003-2006
Associate Professor, Rutgers University (USA).

2006
Appointed by the National Centre for Scientific Research (CNRS) to set up the EPEP team (*Évolution des Protistes et Écosystèmes Pélagiques* - Evolution of Protists and Pelagic Ecosystems) at the Roscoff Marine Station (France).

2009-2012
– Coordinator of the project EU *BioMarKs* project
– Biodiversity of Marine euKaryotes;
– Co-founder of the Tara Oceans Expedition with Eric Karsenti, Gaby Gorsky and Chris Bowler.

2013
Scientific Coordinator of the *Investissement d'Avenir* (Investment for the Future) project OCEANOMICS..

2017
Grand Prix for Ocean Sciences awarded by the French *Académie des Sciences*.

MARINE BIODIVERSITY

TARA OCEANS EXPEDITION

OCEAN PLANKTON FUNDAMENTAL DISCOVERIES THAT WILL SHED NEW LIGHT ON THE WORLD AND THE FUTURE OF THE CLIMATE

1 /
TARA OCEANS EXPEDITION
THE WILD DREAM OF QUANTIFYING AND MODELLING THE EVOLUTION AND THE ECOLOGY OF THE OCEAN PLANKTON

2 /
PROCESSING OF PLANKTON SAMPLES
A UNIQUE DATA BASE

3 /
FIRST RESULTS
REVELATION OF AN UNKNOWN AND UNSUSPECTED BIODIVERSITY

The words followed by an asterisk (*) are defined in the Glossary.

Ph. Fondation Tara Océan

1/ Tara Oceans Expedition
The wild dream of quantifying and modelling the evolution and the ecology of the ocean plankton

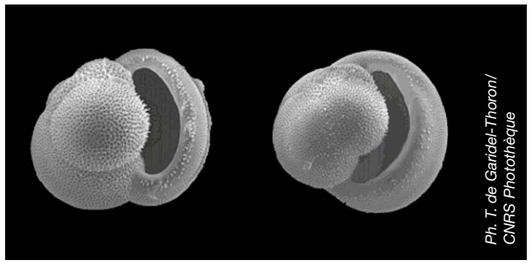
➔ WHAT WAS IT THAT LED YOU TO STUDY THE PLANKTON?

In fact, the plankton attracted me because I'm passionately interested in geology, a science that tracks the history of the Earth. So in the plankton, certain eukaryotic microorganisms are capable of concentrating certain elements of the surrounding water to fabricate skeletons from all kinds of matter, for example calcium carbonates for the coccolithophores*, or silicates – components of glass – for the diatoms*.

In the course of their life cycle, these small cells end up sinking and accumulating on the seabed. There, you can sometimes find expanses of hundreds of kilometres of these small fossil skeletons.

Not many people know this, and when we talk of fossils, large organisms like the dinosaurs often come to mind. In fact, the finest testimony to the history of the planet is recorded at the bottom of the water and of the oceans.

I've always been fascinated by what these fossil archives* beneath the water could reveal, so I started to study the living species that create this parchment record of the history of our planet.



Ph. T. de Garidel-Thoron/ CNRS Photothèque

Foraminifera sampled in the subtropical Pacific Ocean corresponding to the species Pulleniatina obliquiloculata. These calcareous microfossils dating back about 180 million years (secondary era) are studied by palaeontologists to reconstitute ancient climates. Observation by scanning electron microscope.

Several groups of plankton are excellent living microfossils, I've spent a lot of time on them. After a PhD thesis on the evolution of the foraminifera – a group of microfossils - I focused on the coccolithophores*, small algae that I observed through the microscope (*see photos below*). Then I started to take an interest in the group of the diatoms.

> *"The finest testimony to the history of the planet is recorded at the bottom of the water and of the oceans"*

Ph. L. Beaufort/CEREGE/ CNRS Photothèque

Coccolithophore of the species Emiliania huxleyi *– These planktonic unicellular calcifying algae are an important link in the oceanic carbon cycle. A study of their morphology in the natural environment has made it possible to document the changes in calcification over the past 40 000 years in the various oceans. The results show that in general, the coccolithophores calcify less when the seawater is more acidic. This tends to show that the calcareous phytoplankton might undergo major changes in the coming decades if there is an increase in the rate of acidification of the oceans.* Observation by scanning electron microscope.

➔ HAVE YOU CONTINUED IN YOUR CAREER TO ASSOCIATE THIS FASCINATION FOR THE PLANKTON AND THE LIVING MICROFOSSILS?

Actually there was something of a miracle that happened, very quickly, a crossing of paths, as so often in life. A distinguished scientist in cellular biology, Eric Karsenti, had spent much of his life investigating how a cell works. He's also a great sailor, and wanted to do something a bit wild to round off his career.
One day, Eric met the owners of the schooner Tara – The family of the designer *Agnès b.* – who told him: *"We'll let you have the boat, but you have to organise a scientific expedition"*.

At the time, Eric Karsenti wanted to step back from science and was thinking rather of recounting what he'd understood of life and the living world. So there he was, embarked on a real scientific adventure.

This biologist began to consult likely colleagues to go with him on this adventure. So a small group of people formed around him, including me, all chosen because they too had a mildly 'wild' side [(1)].

We soon realised that the aim of the expedition was to try to understand the plankton in all its dimensions. In 2009, it was a rather crazy dream to want to go from the cellular scale to the planetary scale by applying the holistic* science principles of self-organisation. This was a new approach for the ocean, taking into account all the living components of the ecosystem which are organised according to their environment.

>>

(1) See the members of the scientific team led by Eric Karsenti at oceans.taraexpedition.org

Glossary

Coccolithophores
Present on Earth for more than 200 million years, the coccolithophores are small single-cell algae that are exclusively marine. They are part of the nanoplankton, with a size ranging from 5 to 50 micrometres, and are characterised by microscopic calcareous plates, or coccoliths, which cover them entirely. Their sedimentation on the seabed created the chalky geological layers of the Cretaceous. These coccoliths also serve as tracers, as they keep a record of the surface water temperature over the past 3000 years.

Diatoms
Microscopic single-cell brown algae with a membrane encased in a siliceous shell. They are present in freshwater and seawater environments. They are the organisms most widely represented among the plankton.

Fossil archives
Material that bears traces of an 'ancestral' phenomenon, prior even to the emergence of life.

Holistic (science)
Taking something into account in its entirety, without dividing it into parts.

> *"Finally, we live on this planet thanks to a vast quantity of small biodiversity organisms"*
>
> **Romain Troublé**
> Director General, Tara Ocean Foundation
> *France tv nature / 9 june 2020*

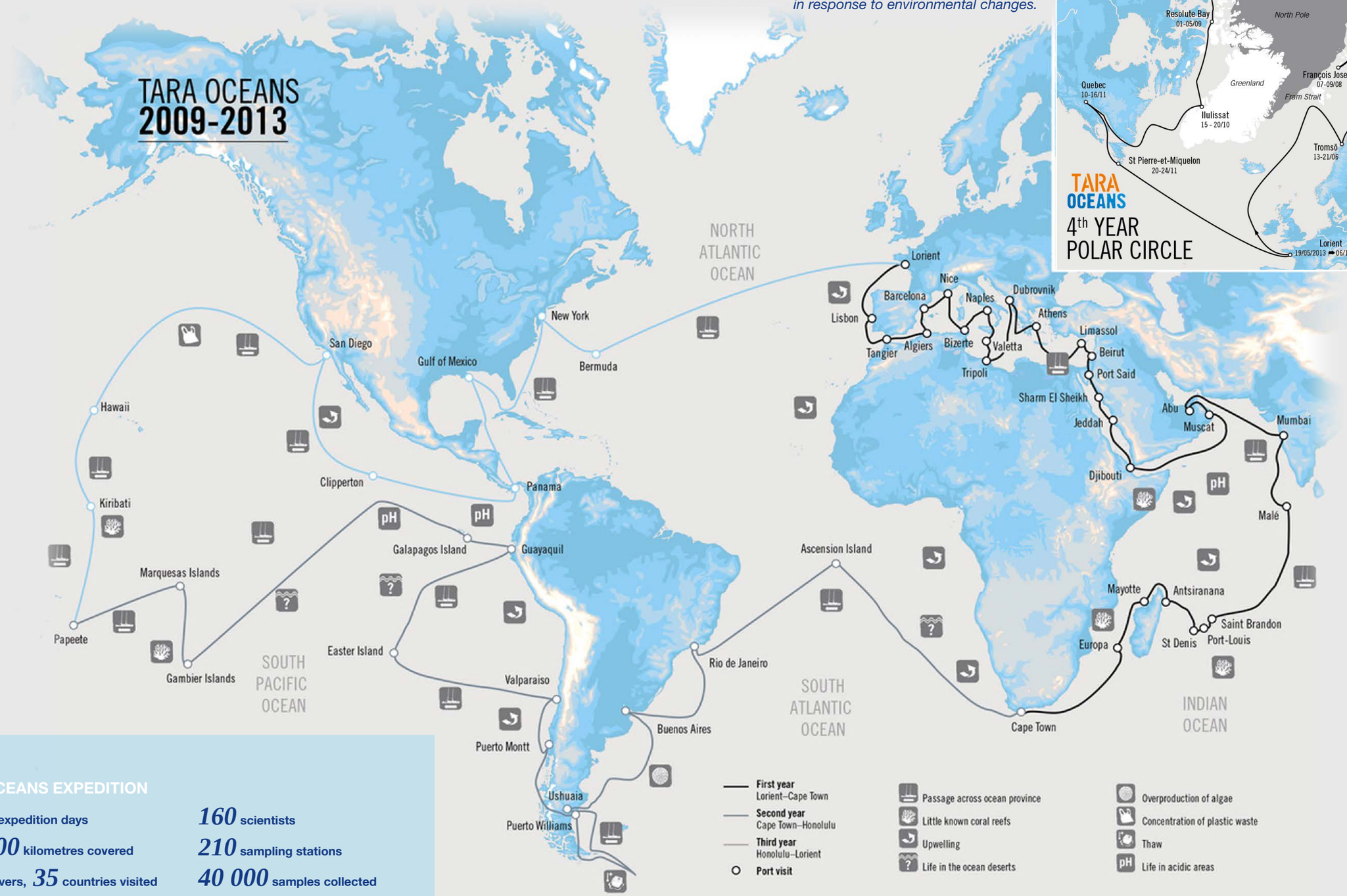
Ph. S. Bollet/FondationTaraOcéan

Ph. F. PLAS/IBENS/CNRS Photothèque

Left: The two-masted schooner Tara is a floating laboratory 36 metres long.
Right: Eric Karsenti, winner of the Médaille d'Or *and Emeritus Director of Research, National Scientific Research Centre (CNRS) - His career has been waymarked by major discoveries, in particular concerning the regulation of the cellular cycle, that is the mechanisms that enable the cells to divide. He was the instigator of the Tara Oceans Expedition, and its scientific director.*

> *“The idea was to characterise exhaustively the planktonic ecosystems: from viruses to animals”*

The schooner Tara sailed around the planet during the Tara Oceans Expeditions *(2009-2012), then the* Tara Oceans Polar Circle cruise *(2013), to understand the global structure of the planktonic and coralligenous ecosystems, and their variations in response to environmental changes.*



Focus

TARA OCEANS EXPEDITION

- ***1 140*** **expedition days**
- ***140 000*** **kilometres covered**
- ***60*** **stopovers,** ***35*** **countries visited**
- ***160*** **scientists**
- ***210*** **sampling stations**
- ***40 000*** **samples collected**

>>

➔ WHAT WERE THE ORIGINAL AIMS OF THE TARA OCEANS EXPEDITION? WHAT OCEANS AND GROUPS OF ORGANISMS WERE CONCERNED?

The idea was to characterise exhaustively the planktonic marine ecosystems: from viruses – the smallest forms of life – to animals, with the bacteria, the eukaryotic cells we call protists, and very small zooplankton animals, including the fish larvae. To achieve this mission, we sailed all around the planet, and rounded off our survey with a trip around the Arctic Ocean [2].

During the expedition, we observed all the plankton species, on the basis of eight orders of magnitude of size. It's gigantic. Imagine that a virus corresponds in size to a bee, then a zooplankton organism, such as for example the lion's mane jellyfish, *Cyanea capillata* [3], would reach the stratosphere! [4]

> *“We systematically carried out the same surveys, the same measurements, at global scale”*

From the practical point of view, a protocol was established at the outset of the expedition to systematically sample all the plankton organisms. We added physical and chemical measurements of the Ocean in order to determine the environmental conditions under which these organisms live.

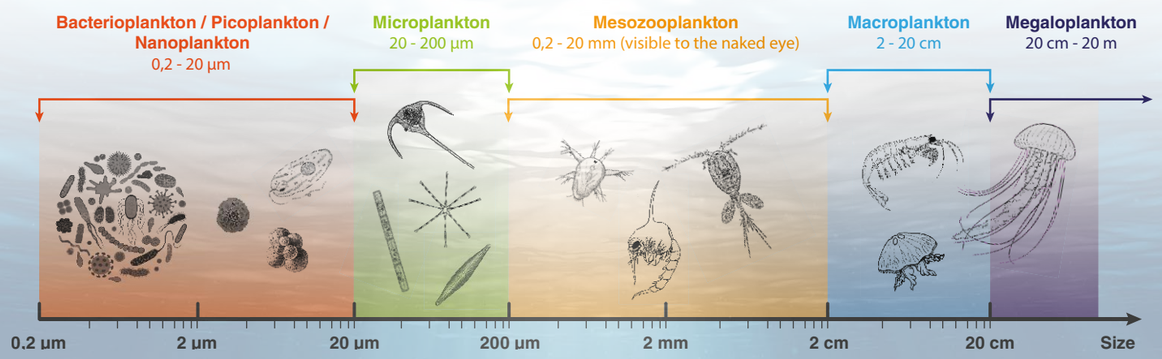
On board, from seven to nine scientists took turns on a permanent basis for five years.

We carried out systematically the same surveys, the same environmental measurements, but we also used the same sampling methods for the organisms over the whole planet.

➔ WHO WERE THE MAIN ACTORS IN THIS PROJECT?

The Tara Oceans project involved twenty or so international teams with ten research centres in France, the others abroad: Japan, United States, Germany. We formed what is known as a consortium.

The core of the programme is located in France, with the National Scientific Research Centre (CNRS), *Sorbonne Université* (SU), the European Molecular Biology Laboratory (EMBL) and the Genoscope French National Sequencing Centre, part of the *Commissariat à l'Énergie Atomique et aux Énergies Alternatives* (CEA). Other French and international teams were also involved, as well as private sector partners: Fonds Tara, Altran, Veolia, Leica, Greentech, Soliance, and so on.



The world of the plankton - Scales of sizes of biological compartments, from microbes to jellyfish (from Sieburth et al., 1978).

➔ WHAT DID THE SCIENTISTS' WORK INVOLVE?

At each of the scientific stations [5], Tara would hove to for two or three days. The scientists took measurements, day and night, really enough to blow your mind. The samples were collected at three depth ranges:
- at the surface;
- from 0 to 200 metres, where the phytoplankton is the most abundant because of the presence of light and nutrients, and a depth where the “deep maximum of chlorophyll” is likely to be found;
- from 500 to 1 000 metres, in the depths, the dark Ocean.

Because of the size of the boat, collecting samples below 1000 metres depth was unthinkable, all the more so because the biological sampling was limited to 500 metres depth.

Because of the size of the boat, collecting samples below 1000 metres depth was unthinkable, all the more so because the biological sampling was limited to 500 metres depth.

Each time, we collected numerous samples of all the organisms encountered. It's complicated, because you have to bring up a lot of water, then filter it to recover these organisms. We also carried out millions of fairly classical physical and chemical measurements, such as the water temperature, the salinity, the pH, the dissolved carbon dioxide, and so on. Finally, we also photographed the plankton in continuous mode to take a vast number of underwater pictures.

>>

(2) During their voyage around the North Pole, the researchers set up 17 microorganism sampling stations and collected some 4 000 plankton samples: from viruses to fish larvae. By providing reference data, this campaign has contributed at international scale to research on the Arctic ecosystem prior to a probable change in the climate regime (source: oceans.taraexpeditions.org).

(3) The lion's mane jellyfish is considered as the largest jellyfish on the planet. Its bell can measure 2.5 metres in diameter. It possesses as many as 800 tentacles that may reach up to 40 metres in length. This planktonic animal lives in the cold waters of the North Pacific, the North Atlantic and the Arctic Circle.

(4) The magic of the power of 10 – Sometimes the numbers go beyond our understanding because it's hard to grasp what they really mean. A small virus measures 0.01 micrometres and a bee 1.5 centimetres, or 15 000 micrometres. Which gives the size of a bee a value one million times greater, or 15 kilometres compared to a virus: the altitude of the stratosphere. As for the largest of the jellyfish, it would reach with its mane-like tentacles the geostationary communications satellites positioned 40 000 kilometres above the Earth

(5) Between its departure from Lorient (5th September 2009) and its return (30th April 2012), the scientists of Tara Oceans set up 210 plankton sampling stations.

Water filtering operation to collect the plankton organisms.

Ph. S. Fretwell/Fondation Tara Ocean

Scientists during sample processing after the morning dive, during the Tara Pacific Expedition (2016-2018), which followed the Tara Oceans Expedition. The aim was to study the hidden biodiversity in a reef, at the same time genomic, genetic, viral or bacterial, in order to compare it with that of the surrounding water mass.

Focus

FROM VIRUSES TO FISH LARVAE...

A GLOBAL AND PLANET-WIDE CHARACTERISATION OF THE PLANKTON ECOSYSTEM

According to Eric Karsenti, the scientific director of the Tara Oceans Expedition, *"the marine plankton is constituted of all the living organisms which drift over large distances in the Ocean, even if many of them, such as the jellyfish, can actively swim short distances"*.

These mostly microscopic organisms are at the base of the marine food chain. They guarantee the survival of the fishes, the marine mammals and thus billions of humans while reacting to the impact of climate change.

Understanding the components of this complex and dynamic ecosystem, its role in the equilibrium of the planet, that is the main goal of the Tara Oceans Expedition.

THE VIRUSES

10 to 100 billion in one litre of seawater

The marine virosphere is immense. It ranges from the phages - viruses of the bacteria - to giant viruses: the giruses.
The oceanic virus populations play an essential role in the transport of carbon from the surface to the seabed: the biological pump*.

THE BACTERIA

1 to 10 billion in one litre of seawater

The bacteria are prokaryotes, that is cells with no nucleus, and certain species, the cyanobacteria, can achieve photosynthesis*. They constitute food for the protists and certain zooplankton animals.

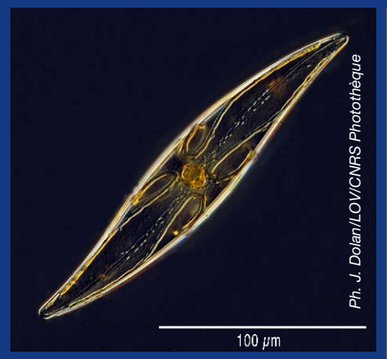
[See page 28: *Biodiversity - Collapse or new-found harmony? Interview with Gilles Boeuf, Chair of the Scientific Council of the Agence Française pour la Biodiversité (AFB)*].

THE PROTISTS, INCLUDING THE PHYTOPLANKTON

1 to 100 million in one litre of seawater

The biodiversity of the oceans is formed mainly of countless species of unicellular organisms possessing a nucleus: the protists. Some of them, such as the diatoms, the dinoflagellates, constitute with the cyanobacteria the phytoplankton that is at the base of the food chain.

Images produced at the Laboratoire de Biologie du Développement, Villefranche-sur-Mer (Alpes-Maritimes, France).

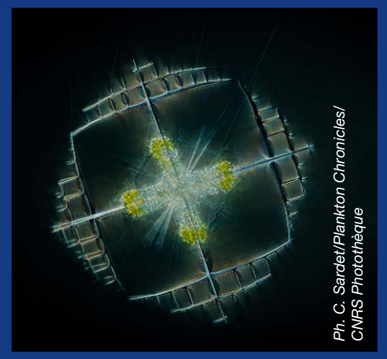


Ph. J. Dolan/LOV/CNRS Photothèque

Diatom sampled at 450 metres depth off the roadstead of Villefranche-sur-Mer, in the western Mediterranean - The diatoms are microalgae which are enveloped in a siliceous external skeleton called a frustule.

Ph. J. Dolan/LOV/CNRS Photothèque

Dinoflagellate, Ceratium pentagonum, *a reddish-orange unicellular microalga, sampled in the South Atlantic during the Tara Oceans Expedition.*



Ph. C. Sardet/Plankton Chronicles/ CNRS Photothèque

Acantharea, Lithoptera mulleri *- This protist has a star-shaped skeleton made from strontium sulfate. It is both animal and vegetal as it feeds on small prey (bacteria and protists) and accommodates within its cytoplasm symbiotic photosynthetic algae (yellow/green parts).*
Sample collected at the Observatoire Océanologique de Villefranche-sur-Mer (Alpes-Maritimes, France).

THE ZOOPLANCTON

1 to 10 000 in one litre of seawater

The animal plankton include small animals such as the copepods, embryos, larvae up to giant animals such a certain jellyfish and siphonophores. They feed on living matter: bacteria, protists or other animals.

Glossary

Biological pump
Major element of the carbon cycle in the sea, it corresponds to a series of biological processes involving the transport of carbon from the surface to the depths.

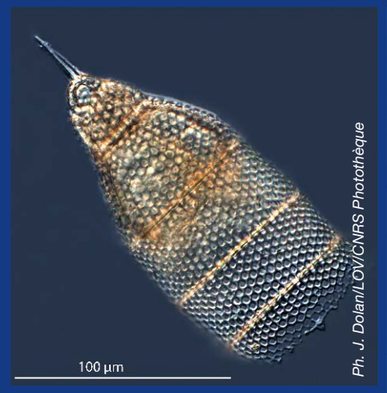
Photosynthesis
A process by which vegetal organisms (algae, plants) and certain bacteria use solar energy to achieve the synthesis of organic molecules from carbon dioxide and water. A biochemical reaction that releases oxygen into the surrounding environment.

Ph. C. Sardet/Tara-Océan/CNRS Photothèque

Pteropod, a small elephant-like mollusc measuring about 5 millimetres. It was sampled in a plankton net from the schooner Tara in the waters of the Indian Ocean, off the Maldive Islands.

Ph. Fondation Tara Océan

Among the great diversity of the zooplankton, we observe among small crustaceans with curious forms such as this juvenile octopus with its red and yellow chromotophores, and a phyllosoma, a larva resembling a spider, typical of spiny lobster and slipper lobster.



Ph. J. Dolan/LOV/CNRS Photothèque

Radiolaria, Eucyrtidium acuminatum, *sampled in the Indian Ocean in a plankton net during the Tara Oceans Expedition. This single-cell animal (protozoan) is part of the zooplankton.*

Ph. C. Sardet/Tara-Océan/CNRS Photothèque

Larva of decapod crustacean - This organism was collected in the Mediterranean Sea during the Tara Oceans Expedition.

Ph. C. Sardet/Tara-Océan/ CNRS Photothèque

Calycophore siphonophores - These gelatinous animals of the cnidarian family are organised in a colony. Each individual is specialised in the capture of prey, digestion, reproduction or floating. More than a hundred species are known worldwide. Organisms collected in the Mediterranean Sea during the Tara Oceans Expedition.

>>

➔ IN PRACTICAL TERMS, WHAT WERE THE TOOLS USED FOR SAMPLE COLLECTION?

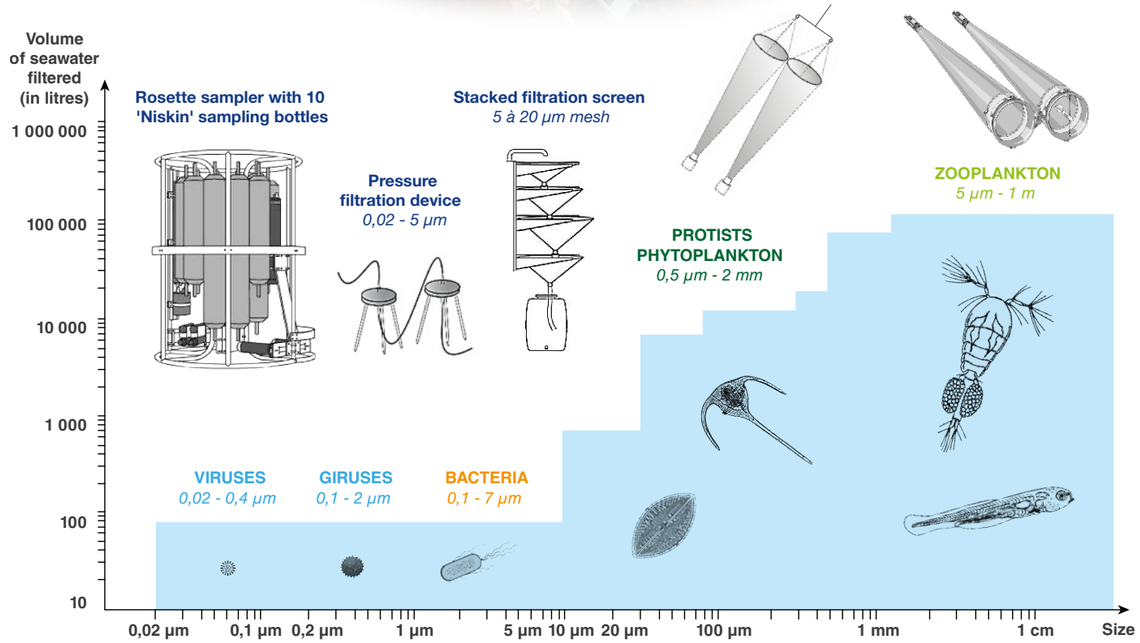
The sampling tools are fairly simple [see page 59: *Sample collection and observation tools – Around 40 000 samples*]. We had at our disposal in particular a big peristaltic industrial pump which could be used to bring large quantities of water on board.

Then the oceanographer's work consists in filtering the water through meshes of different sizes to collect the plankton organisms. The larger they are, the greater the need to filter large amounts of the Ocean water. For the zooplankton, for example, you have to tow large nets and filter the equivalent of whole swimming pools worth of water to collect a small number of specimens.

In four years of the voyage, around 40 000 samples of viruses, microbes and microscopic eukaryotes - from unicellular algae to fish larvae - were collected on board the Tara. It's quite amazing!

>>

Ph. Samuel Bollendorf / Fondation Tara Océan



Plankton sampling method on board the Tara (From the publication: A holistic approach to marine eco-systems biology, 2011). See references in the Bibliography.

Focus

SAMPLE COLLECTION AND OBSERVATION TOOLS

AROUND 40 000 SAMPLES

NETS

The scientists deployed seven types of net, with mesh sizes from 5 to 680 micrometres*, from the surface down to 500 metres depth.

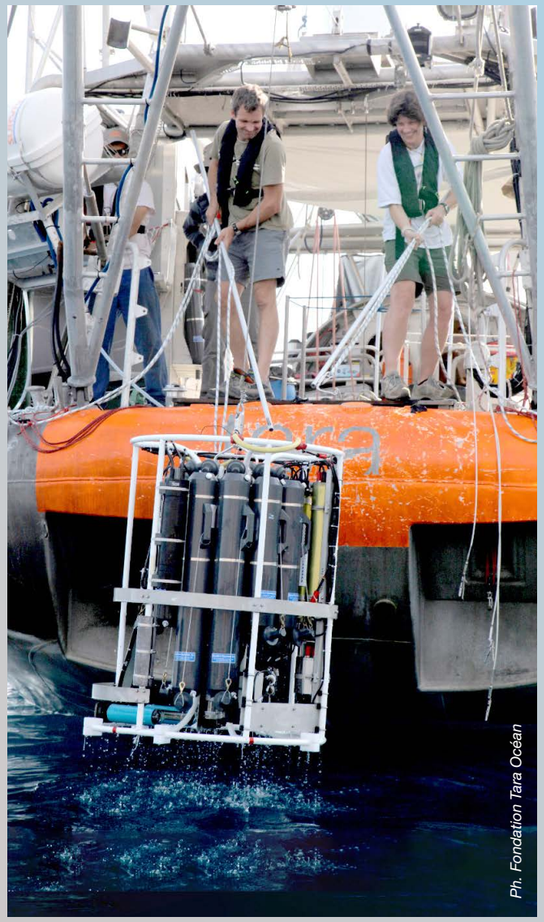
PERISTALTIC PUMP

The Ocean water was collected at depths from 10 to 120 metres. Then it was filtered through sieves with finer and finer filters and meshes in order to sort the organisms by size.

ROSETTE SAMPLER

This setup is constituted of 10 bottles which are programmed to open and collect water at different depths. The samples characterise the water masses: pressure, temperature, conductivity, nitrogen, oxygen, fluorescence, optical properties of the water, and so on.
The rosette is equipped with an UVP (*Underwater Vision Profiler*). This is a camera pointing downwards that films throughout its descent the segment of water illuminated by two horizontal spotlights. A computer uploads the images and counts in real time the organisms measuring between 500 micrometres and a few centimetres.
Fragile structures are thus detected and identified, whereas they would have been crushed in a classical plankton net.
That's the great advantage of this rosette sampler, which combines in one research instrument tools for sampling, measuring the parameters of the environment and photography. And it can do this down to depths of a thousand metres *(source: taraexpeditions.org)*.

Ph. A. Sonlat / Fondation Tara Océan



Ph. Fondation Tara Océan

Ph. N. Floc'h / Fondation Tara Océan

Deployment of a Bongo type net - Its dimensions and its filtration capacity make it an effective tool for searching for rare species, in particular the eggs and larvae of fishes.

Bringing up the rosette sampler. The array of sampling bottles can be seen.

2/ Processing of plankton samples. A unique database

The laboratories of the Genoscope - French National Sequencing Centre, Évry.

Roscoff sequencing platform - Extraction and purification of the DNA. Colomban de Vargas heads the team Évolution des Protistes et des Écosystèmes Pélagiques (EPEP) *(Evolution of Protists and Pelagic Ecosystems), which uses a combination of high-throughput DNA sequencing and imaging techniques to achieve a global understanding of the planktonic ecosystems*

➔ HOW WERE THE PLANKTONIC ORGANISMS COLLECTED ON BOARD THE TARA PROCESSED AND IDENTIFIED?

We dispose of two main types of methods for the analysis and monitoring of marine biodiversity: imaging technologies, on board, and high-throughput DNA sequencing, on land.

The first method is based on imaging. We have on board machines for taking photos of fresh plankton. This technique is valuable because the plankton is very fragile, it is made up of extremely delicate organisms. In fact, it's impossible to bring the samples ashore. If we place them in formol or various other conservation products, they get severely degraded.

The other method is based on the analysis of the genetic material (DNA or RNA), that's to say the expressed genes [6]. On board the Tara, the water was pumped, filtered, and the samples were placed on small membranes that we immersed in liquid nitrogen to be transported and processed on land: not in biology laboratories, but in sequencing centres such as the Evry Genoscope (French National Sequencing Centre) and the Roscoff Marine Station [see page 54: *From viruses to fish larvae: A global and planet-wide characterisation of the planktonic ecosystem*].

When the boat got back to port, we were very stressed because we'd brought back with us several thousand samples to process.

➔ IN PRACTICAL TERMS, HOW WERE YOU ABLE TO PROCESS THESE SAMPLES?

To be able to process the thousands of samples collected in the course of the Tara Oceans Expedition, we had the opportunity to take part in a French government Programme d'Investissements d'Avenir (PIA) (Investments for the Future). I directed this project called OCEANOMICS [7] which consisted in:

- collecting all the plankton samples and the various environmental data;

- producing new data - especially genetic - and performing a lot of high-throughput DNA sequencing at the Evry Genoscope;

- carrying out a huge amount of automatic imaging of plankton at the Roscoff Marine Station, in Brittany (France), and at the Observatoire Océanologique (Ocean Observatory) at Villefranche-sur-Mer, in the Mediterranean ;

- analysing all the information obtained, organising it in databases that are exhaustive and universally available to the scientific community, and extracting the applicable results, in particular in medicine.

In fact, Tara Oceans and OCEANOMICS have generated the largest collection of samples and essential new knowledge on the ecology, morphology and genetics of the plankton. Which makes it, today, the best described ecosystem planet-wide with regard to the organisms and the genomes, from viruses to animals. It's fabulous! [see page 63: *Plankton – High-throughput sequencing that has revolutionised our knowledge of the plankton*].

> ***“We have generated the largest collection of samples and essential new knowledge on the ecology, morphology and genetics of the plankton”***

>>

(6) The cells of an organism all have the same DNA, but only certain genes are expressed in a given cell. The expression of a gene involves the transcription (copying) of a segment of DNA onto messenger RNA. An intermediary support for the information contained in the DNA, the messenger RNA transports the information collected in the nucleus of the cell towards the cytoplasm where it is translated into protein

(7) OCEANOMICS is derived from wOrld oCEAN biOressources, biotechnologies, and Earth-systeM servICeS

3/ First results. Revelation of unknown and unsuspected biodiversity

➔ HOW WERE THE FIRST RESULTS FROM THE EXPEDITION MADE PUBLIC?

These first results represent a whole range of major discoveries on the plankton. The researchers have already published around 130 scientific articles, nine of them in international journals such as *Nature*, *Science* and *Cell*, over the past two years.

In fact, everything's been happening very fast. The data are so fascinating that many researchers have wanted to join us working on this topic of the ocean plankton, all the more so because the data have been made public and are freely available to the whole of the scientific community and to teachers.

Ph. DR

➔ WHEN YOU SET SAIL, DID YOU EXPECT THAT YOU WERE GOING TO ACHIEVE SOMETHING SO EXTRAORDINARY?

No, but as is sometimes the case in all scientific research, we had a kind of intuition, and we embarked. It was when we got back to our home port, Lorient, that we thought: *"It's incredible to have sampled the plankton of the whole planet, at three depth ranges, and above all to have been able to fund the sequencing of all the material we collected."*

In fact, we have established the first base of ecology for the system Earth of a global, holistic* ecosystem, with massive data. This is really a first! And we've been able to do it thanks to the means on board and the support of sponsors.

Glossary

Micrometre
A unit of measurement of length. A micrometre, or micron, with the symbol µm, is equal to 10 -6 m or 0.000 001 metre or 0.001 millimetre.

Hadal (trench)
A region of the Ocean situated below 6000 metres depth. This concerns only about 1% of the seabed and it is characterised by total darkness, temperatures below 4°C and in particular extreme pressure: from 600 to 1 100 times that at the surface. This environment is not devoid of living organisms as had been believed before 1950. The deepest region was discovered in 1875 in the North Pacific. This is the Mariana Trench (10 984 m).

➔ HAVE THE RESULTS TRANSFORMED YOUR VISION OF THE BIODIVERSITY OF THE OCEANS?

Yes, absolutely.
When I signed on for this expedition, I imagined that the biodiversity was constituted above all of very small organisms, such as viruses or bacteria, because at the time the DNA sequencing methods were usually applied to the small fractions of life.

But after the sequencing of tens of thousands of plankton samples, we realised that the biodiversity is not very significant in the world of the small microscopic organisms and that it increases enormously in the 'middle classes' ranging from 5 to 50 micrometres*, mainly protists.

We can now affirm that most of the species and genes are to be found in this fraction of the living world. I think that this discovery is fundamental, and I'd bet my last cent that there's the same distribution of the biodiversity in other ecosystems such as a forest, a coral reef, a desert or a hadal trench*.

We might suppose that it's a general rule and how can we talk of ecology and biodiversity if we haven't really accepted such a pattern of distribution in an ecosystem?

>>

Focus

GENETIC DECODING WHICH HAS REVOLUTIONISED OUR KNOWLEDGE OF THE PLANKTON

To study the complexity of the plankton samples collected during the Tara Oceans Expedition, the scientists have made use of metagenomics*. This is a technique for sequencing and analysing the DNA contained in a composite environment.

By decoding the genetic material of each sample, using a new method of high-throughput sequencing, it is possible to identify the hundreds of species that it may contain without having to isolate them individually, or culture them in the case of microbes, as was done previously.

There is no organism that cannot be processed using this method [see page 56: *From viruses to fish larvae: A global and planet-wide characterisation of the plankton ecosystem*].

The most original aspect of the metagenomics* programme carried out by Tara Oceans lies in its global scale. It is no longer a matter of understanding one particular group, but of describing all of them at the same time. There are in fact numerous modes of interaction between species, such as symbiosis, parasitism and competition, which explains the functioning and the dynamic of the microbial communities, and which can only be understood by studying all the actors.

> *"Around 40 million microbial genes, the vast majority of them new"*

The first results obtained indicate that the genetic diversity of these communities is globally greatly underestimated. *"It is the biggest sequencing operation ever undertaken for marine organisms: the analyses have revealed around 40 million microbial genes, the vast majority of them new, which suggests that the diversity of the plankton might be much greater than we imagined"*, according to Patrick Wincker, director of the Genoscope (CEA).

Metagenomic
Technique for sequencing and analysing the DNA of the genomes of several individuals of different species contained in a particular setting.

Symbiont
Organism which lives in symbiosis, a biological association, sustainable and mutually beneficial, between two living organisms.

The supercomputing expertise of the European Molecular Biology Laboratory (EMBL) has made it possible to create a global catalogue of genetic material estimated at more than 35 000 different species of planktonic bacteria, most of them hitherto unknown.

"For the eukaryotes, we have sequenced almost a billion genetic bar-codings and discovered in the plankton a greater variety of single-cell eukaryotes - or protists - than expected", explained Colomban de Vargas, director of research, CNRS.

"The protists are much more diversified than the bacteria or the animals, and most of them belong to little-known groups of parasites, symbionts and predators of all kinds. In this group, there may be 150 000 distinct genetic types, more than 80% of them phagotrophs, eating each other or living in symbiosis."*

Sources:
- L'avènement de la métagénomique, *F. Quétier, P. Wincker, Dossier pour la science n° 81, 2013 ;*
- Les nouvelles méthodes d'analyse et suivi de la biodiversité marine, *par Colomban de Vargas, TDF Climat, Bordeaux, 2015 ;*
- Premiers résultats scientifiques de l'Expédition Tara Oceans – Plancton : la nouvelle frontière, *CNRS, EMBL, CEA, Tara Oceans, 2015.*


Ph. C. Fréslon/CNRS Photothèque

Genoscope National Sequencing Centre (Evry) – High-throughput sequencer (MiSeq Illumina) that can generate up to 8 gigabases (8 billion de bases) of DNA in only 40 hours.


Ph. C. Fréslon/CNRS Photothèque

Monitoring screen for the sequencing of samples.


Ph. C. Sardet/Tara Ocean/CNRS Photothèque

Various protists collected in the Indian Ocean during the Tara Oceans Expedition.

>>

> *We're beginning to get enough data to understand the reaction of the ecosystem of the plankton globally in the face of climate change*

➔ DO THESE DISCOVERIES MEAN THAT WE MIGHT BE ABLE TO BETTER UNDERSTAND THE ROLE OF THE MARINE ECOSYSTEMS, IN PARTICULAR THE PLANKTON, IN THE CLIMATE MECHANISM?

We know that all the planktonic organisms are highly reactive to climate change and that their own changes influence the environment. We recognise that there is a high degree of reactivity and retroactivity in the plankton, which transforms the world physically and chemically.

Through photosynthesis*, part of the plankton constituted of microalgae absorb the carbon dioxide from the atmosphere and produce more than 50 % of the oxygen in the air we breathe [8].

Identifying the richness and the functioning of the biodiversity is thus essential for understanding the climate regulation processes which are generated by living organisms.

With Tara Oceans, we have established a reference base on the state of the world's plankton.
For the moment, there is practically no historical background of measurements, and it is only from this reference base that it will be possible to record changes in the plankton and its capacity for adaptation to global change. This is very important, and is one of the major issues for the world climate.

Along the same lines, we have published an article in the journal *Nature*. It explains that the data are so complex that we are trying to constitute networks of species living together. A kind of plankton *Facebook*!

Then, we correlate these networks of interactions of species to phenomena that have an important role for the climate, such as the biological pump*, or factors related to climate change such as the acidification and the heating of the waters. So we are trying to understand the reactivity of these networks in relation with these phenomena.

We are beginning to have enough data to characterise the behaviour of the plankton ecosystem as a whole in the face of climate change [see page 65: *Impact of climate change on the plankton – The tropicalisation of the temperate and polar oceanic regions*].

To this end, mathematicians and computer scientists are joining in the analysis of our results to describe the phenomena observed as equations. This may open the way to the construction of mathematical models of the evolution of the ecosystems concerned in function of environmental changes.

➔ WILL THE TARA OCEANS EXPEDITION ALSO ENABLE US TO BETTER UNDERSTAND THE EVOLUTION OF MARINE LIFE, PERHAPS EVEN ITS ORIGINS?

This is a topic I'm passionately interested in because, for the moment, the theories at play regarding change and the evolution of life are focused on Darwin's theory, that is that there are organisms that seem very alike and which are selected for their traits, their phenotypes. And natural selection means that the most successful of them survive and have more descendants.

I have reservations regarding this theory. In reality, what we have often observed in the course of our expedition is the fact that all the plankton organisms interact with each other. This is quite fascinating: we see that a large number of small organisms are placed on top of or within larger organisms to form small consortiums of life.

The term holobiont [9] was invented by an American biologist to designate this phenomenon, that is to say the constitution of a super-organism which is composed of 'little worlds', in fact small ecosystems

>>

(8) To find out more: The Ocean, Master of the Climate - *Interview with Dr Françoise Gaill, Emeritus Director of Research, CNRS, Vice-President of the Ocean and Climate Platform,* Newsletter of *the Institut océanographique Paul Ricard, n° 14, 2015.*

(9) The word holobiont was used for the first time in 1991 by Lynn Margulis, an American biologist and symbiosis specialist, to describe a creature resulting from the collaboration between species.

Focus

IMPACT OF CLIMATE CHANGE ON THE PLANKTON

THE TROPICALISATION OF THE TEMPERATE AND POLAR OCEANIC REGIONS

The plankton species are unevenly distributed in the Ocean, and they are likely to adapt differently to environmental conditions between the equator and the poles. This is what is shown by the results of two studies published on 14th November 2019 in the journal *Cell*.

> *The diversity of the plankton is greater around the equator and diminishes towards the poles*

The first study directed by Lucie Zinger, associate professor at the *École Normale Supérieure-Université Paris Science Lettres* (ENS-PSL), and Chris Bowler, director of research, CNRS, consisted in analysing the data collected at 189 sampling stations during the Tara Oceans Expedition.

The aim was to identify the diversity of the main groups of plankton in order to map their worldwide distribution and to obtain information regarding their response mechanisms to climate change. *"Our results show clearly that the diversity of the plankton is greater around the equator and diminishes towards the poles"*, explains Lucie Zinger.

> *The primordial influence of the temperature on the distribution of the plankton species*

In parallel, the team led by Shinichi Sunagawa, associate professor at the Swiss Federal Institute of Technology, Zürich, exploited the DNA and RNA sequencing data from Tara Oceans, generated by the Genoscope.

The team used these elements of information to analyse the activity of the microbial communities, the ultimate goal being to understand the capacity of the microbes to adapt to environmental changes. *"These analyses enabled us to study not only what the oceanic microbes are capable of doing, but also what they are doing at worldwide scale"*, explained Shinichi Sunagawa.

The activity and diversity of the microbes remain stable between the equator and 40° latitude, then they rapidly change by stages to about 60° latitude, where a new stable state is apparent. These two ecological limits (one to the north of the equator, one to the south) correspond to precise physical and chemical changes in the surface waters, mainly a significant drop in the temperature.

Archaea
Prokaryotic unicellular microorganisms, that is to say living organisms constituted of a single cell with neither nucleus nor organelles, like the bacteria.

The new maps of the diversity of the plankton realised by Lucie Zinger's team show that there are similar limits for all the plankton species: from the bacteria to most of the viruses and the archaea*, the protists and the zooplankton. Here too, the temperature would appear to be the major factor explaining these tendencies.

The primordial influence of the temperature on the distribution of plankton species raises obvious questions in the current context of climate change.

On the basis of the most recent and the most accurate models of the IPCC (International Panel on Climate Change), Lucie Zinger's team, in collaboration with Laurent Bopp, director of research at ENS-PSL, predicted the possible evolution of this plankton biodiversity.

These predictions show clearly that the highest ocean temperatures are likely to give rise to a tropicalisation of the temperate and polar oceanic regions, with higher water temperatures and greater diversity of plankton species. These regions are currently of great importance for environmental and economic reasons:
- They play a crucial role in capturing carbon dioxide and storing it in the Ocean;
- They are very active fisheries zones, and large areas of these waters are protected to provide a refuge for endangered species.

The most important changes with regard to diversity should occur within these regions, consequently altering the associated ecosystems with grave repercussions at worldwide scale.

Source:
The Tara Oceans mission has revealed the variations in the biodiversity of the plankton and of its activity, from the equator to the poles. Fondation Tara Océan, press release (14th November 2019).

Ph. F. Latreille/Fondation Tara Océan

Tara in the sea ice during the Tara Oceans Polar Circle expedition. This schooner, originally called Antarctica, has no keel to prevent it getting trapped in the ice.

>>

We now know that a human is itself an ecosystem in harmony with more bacterial cells in our body than human cells.
I believe that we are beginning to understand that the evolution of life functions rather thanks to collective behaviour, that is to say organisms work together, exchange mechanisms, know-how, sometimes genomes. And then they begin to be organised into super-organisms, superstructures that work even better than initially. It's fabulous!

We formulate the hypothesis that these super-organisms become more complex through mechanisms of symbiosis, of living together, ultimately generating a collective power. Nothing to do with Darwinism, but really the expression of mechanisms which, by complexifying life, make it evolve.

Of course, selection plays a part, that is to say the pressure of the natural environment determines whether a system is viable or not. But the creative force of evolution is really based on this collective force. It is not a destructive force causing the disappearance of a species that doesn't adapt. That's a bit grim as a theory!

➔ CAN THE PLANKTON REPRESENT AN INTERESTING LIVING RESOURCE, IN PARTICULAR IN THE EXPLOITATION OF MOLECULES THAT CAN BE USED IN MEDICINE?

With Tara Oceans, we have sequenced 250 million new genes, and we don't even know what is the role of 60% of them, while the plankton does not appear to be particularly rich in species. It is one of the simplest ecosystems on the planet.

On the other hand, we are sure that the plankton represents a fabulous resource for the future.

Today, most medical drugs come from extracts or derivatives of terrestrial plants. We are beginning to dispose of a few marine bioactive* molecules from coral reefs, algae, sponges, some of them possessing anticancer activity. Now that we're starting to take an interest in the plankton, it's certain that we'll discover natural substances that are very interesting for human health and for a wide range of technologies, biotechnologies and nanotechnologies*.

The States do not always understand the interest of investing major funding in these programmes of exploration of the living world. Yet, even if it is not predicted at the outset, it's virtually certain that we'll make discoveries which will shed new light on the world. The risk of failure is slight, contrary to what might be supposed.

Glossary

Bioactive (molecule)
A molecule that possess physical and chemical properties which have a beneficial effect on the metabolism of a living organism.

Nanotechnology
Technology that involves objects at molecular or atomic scale.

➔ WHENCE THE NEED TO PRESERVE THIS BIODIVERSITY...

Yes.
With each species lost, millions of years of life disappear irreversibly. A real heritage constituted of an accumulation of natural inventions is lost forever. A loss of biodiversity is a terrible thing. We must do everything we can to preserve it.

➔ AREN'T YOU BEING RATHER OPTIMISTIC, ISN'T THERE A RISK THAT THERE WILL BE A TOTAL COLLAPSE OF THE BIODIVERSITY?

Sometimes, I'm only half optimistic when I think of the negative dominion that the human species has over nature.

The worst thing is that we are always wondering when we will become a little less avid in our consumption of energy, less selfish, more generous. The inequalities between people are widening, and today, the major problem for the planet is the full panoply of changes that we are inflicting on it.

It is obvious that the planet will outlive us, and it's very arrogant to think that it will be possible to transform it. It is the planet that will make us suffer a lot of hardships, and human populations will suffer from them if we continue heading in this direction.

Nature's equilibrium will quickly get the upper hand again, as the history of life on Earth has shown.

I'm not worried at all, given the diversity that we have discovered in the marine plankton. Even if to lose one species is still a dramatic loss, I can't even tell you today how many there are on Earth.

I believe deep down that we only know a minute percentage of the biological diversity of current species. So there is a resource, a resilience, a life force that are infinitely greater than us.

Talking about these aspects, we are thinking rather of the survival of humanity. It would after all be a pity if a beautiful species didn't continue to exist on this Earth.
In fact, saying that, I'm thinking of my children.

➔ HAS THERE BEEN A FOLLOW-UP TO THE TARA OCEANS EXPEDITION?

The schooner *Tara*, which is owned by Étienne Bourgois, president of the *Fondation Tara Océan*, has been involved in several scientific programmes: Tara Pacific for the coral, then Tara mission microplastics.

There's another project that I'm particular attached to after Tara Oceans. I think that to improve out knowledge of the functioning of the world of the plankton, we have to carry on with global measurements and repeat what we did during our expedition.

Now there are some 10 to 15 000 yachts permanently sailing around the oceans. I would wish that the sailors, yachtsmen, ocean racers, and even the captains of cargo vessels, why not, all volunteers, should form an international fleet and contribute to the measurement of the ocean plankton by collecting samples. For that, we've prepared a simple protocol, a *planktoscope*, based on the experience of the Tara Oceans Expedition.

When we show this tool to the mariners, they're fascinated: in fact, it's because they adore the Ocean in general. They discover how full of life it is, how full of beautiful things. This adds a new level of interest to their voyages.

I think that of we can manage to achieve this scenario of citizen sailors, people are going to make discoveries. And we could dispose of an ongoing process of measurement of the ocean plankton. This is necessary because it changes, there is constant alteration, very quickly, much more quickly than the forests, for instance.

Ecosystem approach
A method based on the idea that all the parts of an ecosystem are related. This implies that all of them should therefore be taken into account.

➔ IN 2017, YOU WERE AWARDED THE GRAND PRIX DES SCIENCES DE LA MER BY THE ACADÉMIE DES SCIENCES. WHAT DOES THIS DISTINCTION REPRESENT FOR YOU? IS IT A STEP TOWARDS OTHER RESEARCH?

This prize is a great source of pride for me. It is very rewarding to see your work recognised by the scientific community in the presence of one's family. It's a great encouragement to carry on with one's work.

This prize wasn't really the end of a cycle, because at the beginning of my research, I studied organisms one by one, and then, with Eric Karsenti, I moved on to a more complex scale than the simple cell: the ecosystem.

The Tara Oceans Expeditions marked the beginning of a new cycle of an ecosystem* approach for the plankton. We are among the pioneers in this field, and we have 30 or 40 years of research ahead of us… ■

Interview with Christian Frasson-Botton
February 2020

BIBLIOGRAPHY

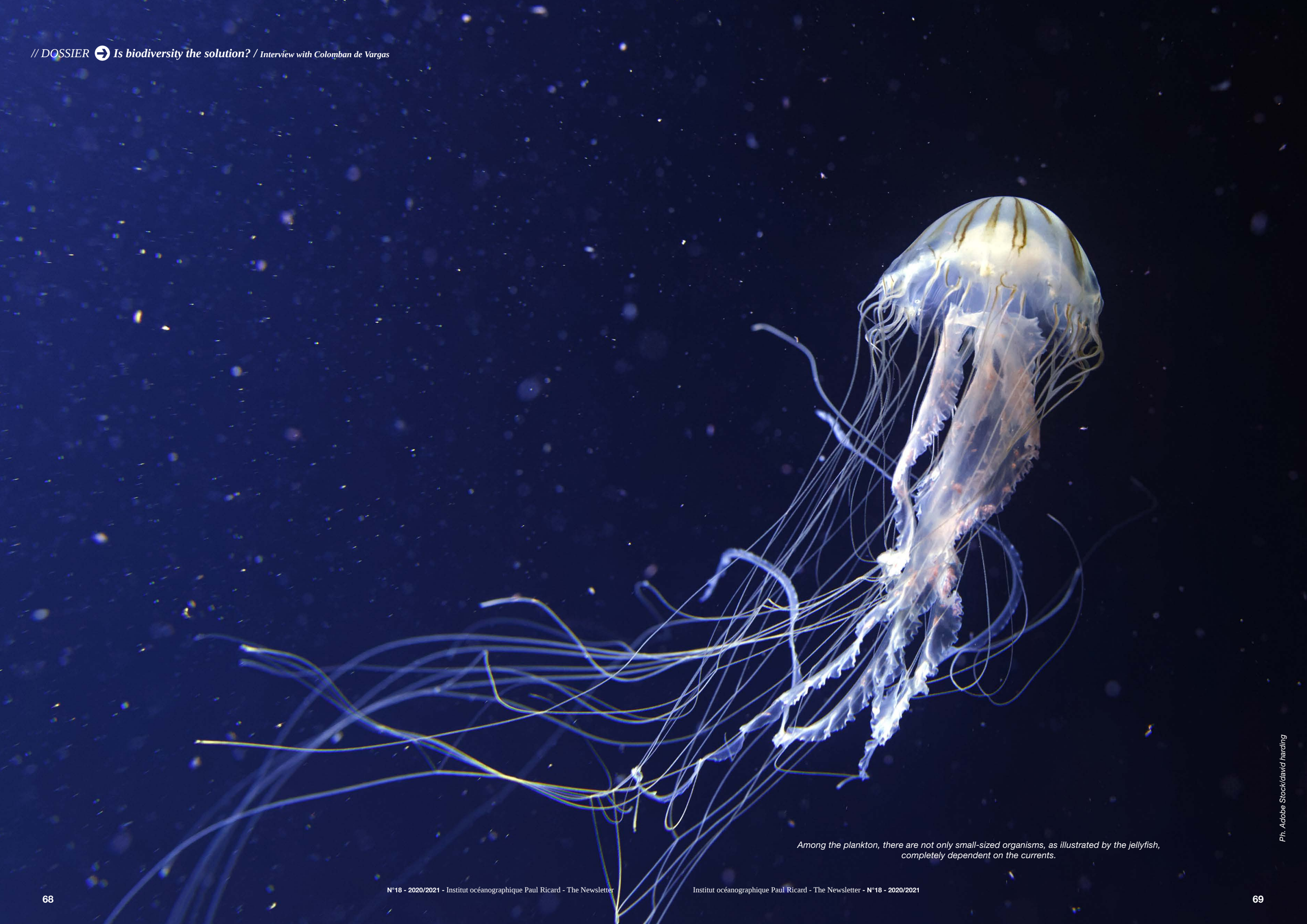
• Flora Vincent, 2019 - *Plancton, la nouvelle frontière.* planet-vie.ens.fr/thematiques/ecologiebiodiversite/plancton-la-nouvelle-frontiere

• Éric Karsenti, 2018 – *Aux sources de la vie*, Flammarion.

• Stéphane Pesant et al., 2015 - *Open science resources for the discovery and analysis of Tara Oceans data.* Nature.com/articles/sdata201523.

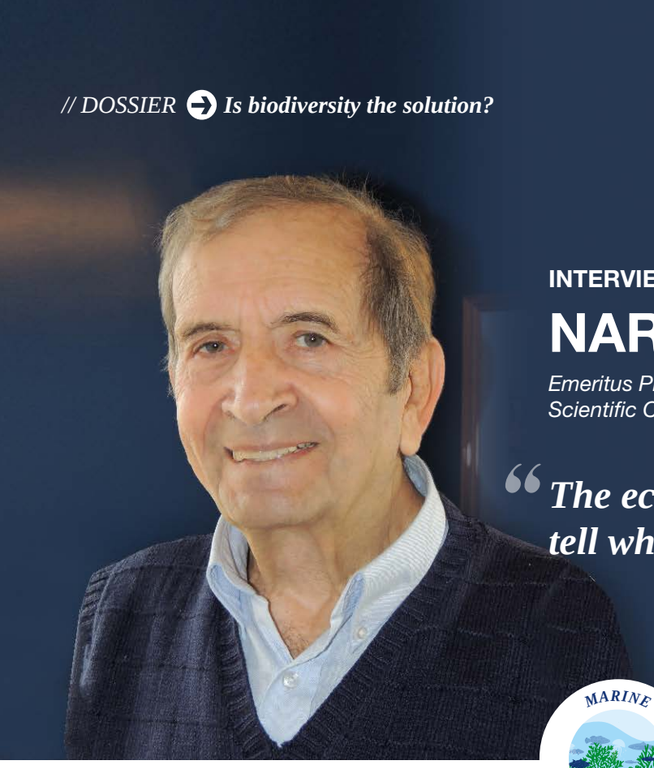
• Éric Karsenti et al., 2011 - *A Holistic Approach to Marine Eco-Systems Biology*. PLoS Biol. 2011 Oct; 9(10): e1001177.

Ph. Adobe Stock/Netfalls



Among the plankton, there are not only small-sized organisms, as illustrated by the jellyfish, completely dependent on the currents.

Ph. Adobe Stock/david harding



Ph. C F-B

INTERVIEW WITH

NARDO VICENTE

Emeritus Professor of Marine Biology, Aix-Marseille University (IMBE)
Scientific Counsellor, Institut océanographique Paul Ricard

> *“The ecosystem will evolve, but we can’t tell whether or not it will be poorer”*

FOR MORE THAN 60 YEARS, PROFESSOR VICENTE HAS BEEN EXPLORING THE SEABEDS OF THE MEDITERRANEAN FOR HIS RESEARCH WORK. AS A PRIVILEGED WITNESS, HE HAS REVIEWED FOR US THE CHANGES IN ITS BIODIVERSITY, THE FUTURE ISSUES AND THE CHALLENGES TO BE MET TO PRESERVE IT.

➔ YOU HAVE BEEN DIVING IN THE MEDITERRANEAN FOR 60 YEARS: AS YOU RECOLLECT, WHEN DID WE START TALKING OF CLIMATE CHANGE?

We have been talking of climate change in the Mediterranean since the beginning of the 1990s: very high temperatures began to be recorded over long periods, sometimes lasting from spring to autumn. We remember for instance the crisis of 1999 which impacted the purple gorgonians on the coralligenous walls, amazing living environments. The branches, constituted of polyps, which are colonies of animals, were in decline, and on some walls the gorgonians had practically disappeared. This of course alerted the marine biologists. We wondered whether this phenomenon was solely due to the warming of the water, but we realised that the rise in temperatures coincided with bacterial development. In the environment, there are considerable quantities of viruses which we still don’t know much about, germs, parasites, which are dormant, and which, if the warming persists, may proliferate. And over the past decades, these problems of the persistence of very high temperatures have become more and more recurrent.

➔ WE TALK TODAY OF AN ALTERATION OF THE BIODIVERSITY, PARTLY LINKED TO THIS RISE IN TEMPERATURES...

Rather than an alteration, I would rather talk about an evolution of the biodiversity. It’s a very longstanding phenomenon, it dates back to Darwin’s work in the 19th century, in the Mediterranean and elsewhere in the World Ocean. One might say it is normal, but it’s going faster and faster, precisely because of climate change. Today we can observe the disappearance of species a thousand times faster than during the first massive extinction [(1)], when more than 70% of marine life became extinct. What is certain is that today there is a tropicalisation of the Mediterranean: new species, more and more of them, and including all the zoological groups, are arriving via the Suez Canal from the Red Sea; these are what are known as the Lessepsian species. For example, there are twenty or so new species of nudibranchs, sea slugs, while many of the local species have disappeared over the course of time. All these invasive species have begun to colonise the eastern basin, and then, gradually, they reach the western basin. And some manage to settle and become competitors of the local species.

>>

(1) The first extinction occurred in the Primary or Palaeozoic age, about 445 million years ago.

Ph. Adobe Stock/Damedias

Shoal of seabream Sarpa salpa, one of the few herbivorous fishes in the Mediterranean, above a Posidonia oceanica seagrass meadow.

> *“What is certain is that today, there is a tropicalisation of the Mediterranean”*

Ph. P. Lelong

With the warming of the water, certain formerly rarely observed species, such as the barracuda, Sphyraena vitidensis, are becoming increasingly frequent.

CAREER

1936
Born in Barcelona (Spain).

1960
Assistant Lecturer, *Faculté des Sciences de Marseille*.

1967
PhD in Marine Biology, *Université d’Aix-Marseille. Faculté des Sciences et Techniques de Marseille-Saint-Charles*.

1968
Lecturer *(Maître de Conférence), Université d’Aix-Marseille III. Faculté des Sciences et Techniques de Marseille-Saint-Jérôme*.

1972
Scientific Counsellor, *Institut Océanographique Paul Ricard*.

1975
Full Professor, Director of the *Centre d’Etudes des Ressources Animales Marines, Faculté des Sciences et Techniques de Saint Jérôme (Université Aix-Marseille III, later Université Paul Cézanne)*.

1982-2011
Course Director of post-graduate course in Marine Biology and Applied Oceanology, *Station Marine de Tuléar (Madagascar). Université de Tuléar*.

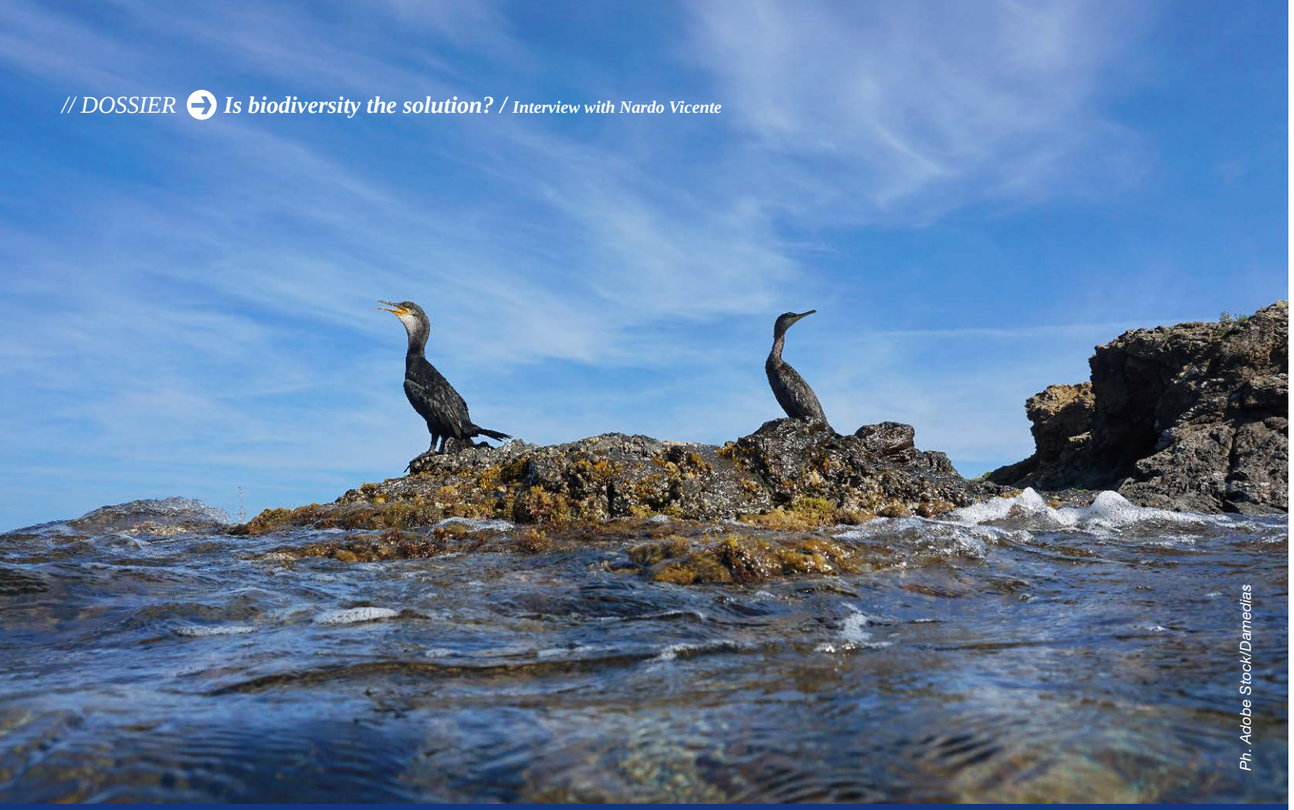
1989-1995
Member of the Marseille City Council, delegate for the protection and valorisation of the littoral.

1998
Member of the *Académie des Sciences, Lettres et Arts de Marseille*.

Depuis 2004
Emeritus Professor of Biology, Aix-Marseille University (*Institut Mediterranéen de Biodiversité et d’Écologie* - IMBE).

Ph. L. Miard

Prof. Nardo Vicente in the laboratory at the Institut océanographique Paul Ricard, with one of the research team, Damien Kirchhofer.



Two cormorants, one of the birds that is emblematic of the Mediterranean rocky coasts. Expert divers, they feed on the fishes that are abundant in the first two metres of water.

The preservation of the shallow coastal waters, alternating rocky bottoms, sandy areas and seagrass beds, is an essential condition for the maintenance of Mediterranean biodiversity.
Safeguarding the Posidonia oceanica *meadows, a major ecosystem, the habitat and breeding ground for numerous species, calls for improved awareness and information for the public, in particular with regard to the mooring of pleasure craft.*

// DOSSIER ➔ Is biodiversity the solution? / Interview with Nardo Vicente

>>

The yellowmouth barracuda already existed but the current populations are becoming more and more numerous. In the Port-Cros National Park, for example, around the islet of La Gabinière, in the no-take zone of the Park, some 400 barracuda which remain motionless during the day go hunting at night, and are in competition for food with species such as the leerfish and the dentex. You hear a lot today about the rabbitfish, I have seen some at Carry-le-Rouet. It's a herbivore*, it's in direct competition with our seabream *Sarpa salpa*, and no doubt in time it will gradually replace it.

Others, such as the *Lagocephalus*, hitherto unknown, have begun to be regularly observed. This boxfish, which closely resembles the Japanese *fugu*, should like the *fugu* be prepared with great care to eliminate the parts that contain poisons, or neurotoxins; if not... A *Lagocephalus* was caught and eaten in Tunisia, and five people died.

The Mediterranean represents less than 1% of the World Ocean, and we know that it possesses 9 to 10% of the total biodiversity. We refer to it as a biodiversity 'hotspot'. More than half of the Mediterranean species are of Atlantic origin, 28% are endemic, and 20% occur everywhere. By the end of the century, the Atlantic species will no doubt no longer be with us. The ecosystem will evolve, it will be different, but we can't tell whether or not it will be poorer.

The silver-cheeked toadfish, Lagocephalus sceleratus, *also threatens to upset the equilibrium of native species, and is too a danger to health. It is highly toxic, and several people have already died after eating it in Mediterranean countries.*

➔ CLIMATE WARMING ALSO ENTAILS, AS YOU WERE SAYING, THE 'AWAKENING' OF CERTAIN PARASITES. ARE SOME SPECIES TODAY THREATENED WITH EXTINCTION?

We can't say today that species have already disappeared, but at least 300 of them are vulnerable. And among them, there is a flagship species endemic* to the Mediterranean, which I've been working on since the 1970s, the fan mussel, the world's largest shellfish along with the tropical giant clam. Since the industrial age, it has been in danger of extinction because of boat anchors, trawling, coastal construction work that has led to the disappearance of its breeding grounds, which are found at depths of four to eight metres, and of course unlawful harvesting since the development of scuba diving.

What scuba diver over the age of 50 hasn't at one time or another collected a fan mussel? I've done it, because when it was the first time I'd seen this species, I was amazed that a huge mussel like that could be growing in the Mediterranean! I began to work on this species at Port-Cros in 1970, after the discovery of a field of fan mussels by Commandant Philippe Tailliez, the father and pioneer of modern diving. At the time he was a member of the scientific council of the Port-Cros National Park, and he told me: *"Young man, you should take care of these charming little animals"*: 'little animals' that can when fully grown measure one metre and live for more than 40 years!

The protection of this species, introduced in 1992, had enabled the populations to be to a large extent reconstituted. But since 2016, massive mortality has been observed. This phenomenon started on the Spanish coasts in September 2016, and rapidly spread to the Balearics then Ajaccio in Corsica by 2017, with a mortality rate of 80 to 100%. And this was due to a parasite which we thought we already knew about as it had decimated the oyster industry in California in 1957, after arriving in the ballast waters of a Japanese freighter. We thought it was the same species, but it wasn't. This new species was identified by the specialists at a research laboratory in the Balearic islands, it is specific to the fan mussel, and so it was given the name *Haplosporidium pinnae*.

Glossary

Herbivore
Species which feeds exclusively on plant matter.

Endemic species
Designates a native species (animal or vegetal) that is found in a particular region and which has a relatively limited range of distribution.

Fan mussels in a Posidonia oceanica *meadow, its favourite habitat (Photo: P. Lelong).*

>>

This *Haplosporidium* has begun to spread throughout the Mediterranean: in October 2018, at Scandola, at a depth of forty metres, the temperature was 22 degrees. In August the same year, researchers at Villefranche-sur-Mer (SE France) called me to report that in the bay it was 26 degrees at 60 metres depth… 30 years ago, at that depth, it was 13 degrees all year round and what we call the thermocline was at about twenty metres depth. Today, for one thing the deep water temperature is 14 degrees, and for another you have to go deeper and deeper to find it. So parasitic diseases are likely to affect more and more species, as in the case of the red coral, for example, which has begin to decline at Scandola, right inside the reserve, whereas it is a very important resource.

> ***“Parasitic diseases are likely to affect more and more species, as in the case of the red coral, for example”***

➔ THE ECOSYSTEMS ARE GOING TO EVOLVE BUT PROTECTING THEM REMAINS VITAL. WHAT IS THE IMPACT OF THE MARINE PROTECTED AREAS ON THE PRESERVATION OF BIODIVERSITY?

In my view, the two key examples as concerns the study of biodiversity in the Marine Protected Areas (MPA) are Port-Cros (SE France), the first to be set up in 1963, then the Scandola natural reserve (Corsica), which dates back to 1975. Work that has been done there has enabled us to better understand the ecosystem itself, and above all to know the various species of which it is constituted. The specialists have been active at these two marine areas which now, fifty years later, have become wildlife sanctuaries. And then we have another more recent example, the Calanques National Park (near Marseille, SE France), which only dates back to 2012, and so far we only have a few indicators for the resilience* of the ecosystem. But as soon as an area is protected, we can observe that the species reproduce better, they are more numerous, they grow bigger, they produce larger quantities of eggs, this is the case for the fishes, for example, and so for the fry which then enrich the environment, and which will provide a resource for the local fishery, that is the artisanal fishery, the only kind that is perfectly integrated in the ecosystem, and which should therefore be supported.

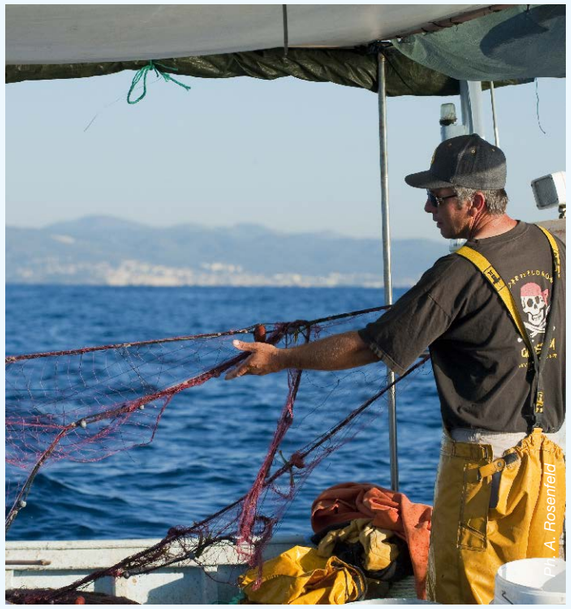
>>

Glossary

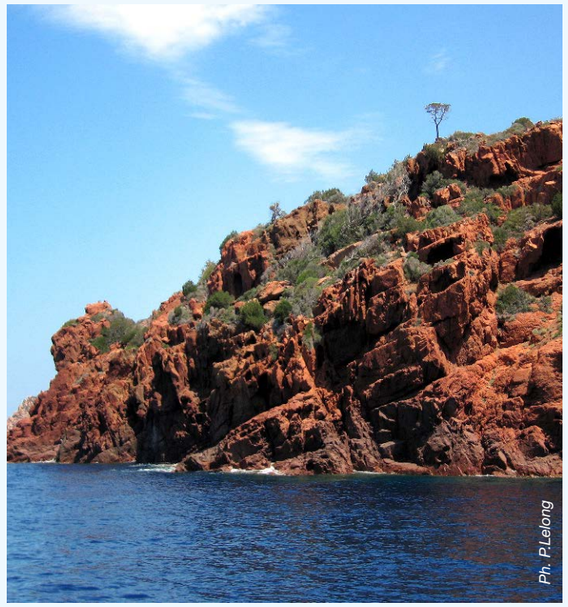
Resilience
Defines the capacity of a living system (ecosystem, population, biosphere, etc.) to recover the structures and functions of its reference state after a disturbance.

Yellow gorgonians, Eunicella cavolinii, *in the Calanque de Podestat, in the heart of the Calanques National Park.*

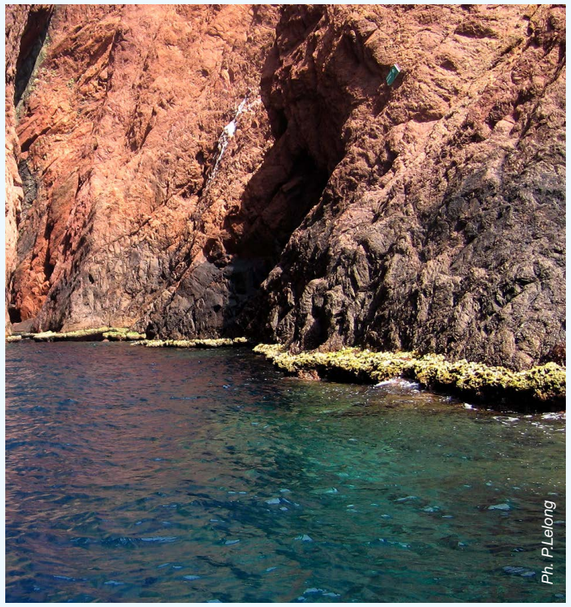
Colony of red coral, Corallium rubrum, *under a rocky overhang. This species, like others, seems to be directly threatened by the prolonged warming of the waters of the Mediterranean.*



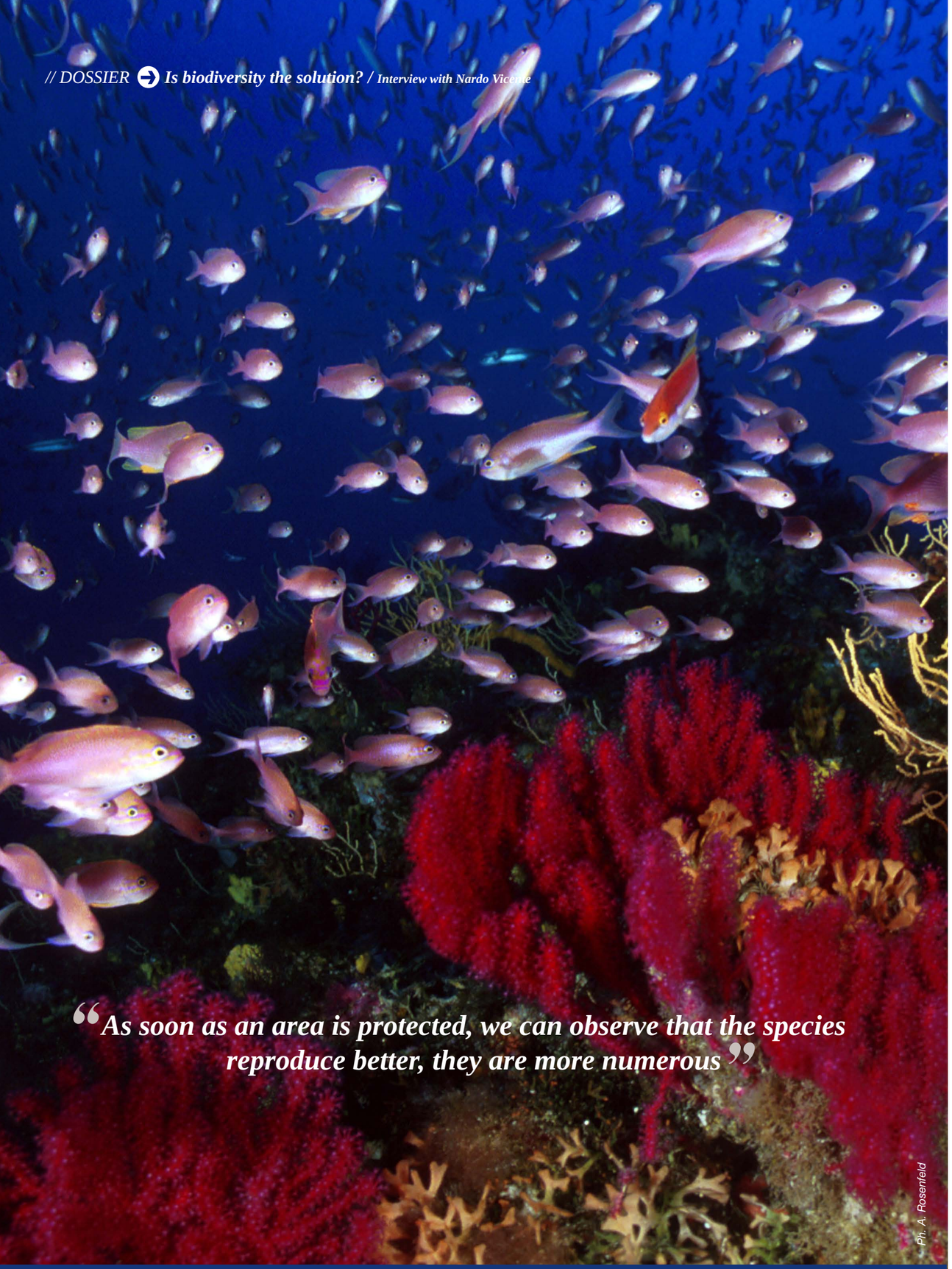
Artisanal fishing, carried out on small boats and using appropriate methods, is compatible with safeguarding Mediterranean biodiversity.



Red rocks characteristic of the Scandola Marine Reserve, currently the only site in the Mediterranean classified as Marine World Heritage by UNESCO, has had protected status since 1975.



At the bottom of the cliffs, we can see a coralligenous platform, formed by a calcareous alga, Lithophyllum byssoides. *Its good state of health is an indicator of the water quality.*



An explosion of life in the waters of the Île du Levant (SE France). Shoals of swallowtail sea perch, Anthias anthias*, swimming among forests of red gorgonians,* Paramuricea clavata*.*

// DOSSIER ➔ Is biodiversity the solution? / Interview with Nardo Vicente

>>

➔ CAN WE SAY THAT THE SPREAD OF MARINE PROTECTED AREAS IS THE SOLUTION TO MAINTAIN BIODIVERSITY?

The experiments we have cited have shown it, and so on that basis more and more Marine Protected Areas have been set up throughout the Mediterranean. There are now a hundred or so, and they work well, with effective management. Their managers work within a network called MedPan, they are in constant contact with each other, and this means they can see how the biodiversity is evolving, whether it is in decline in some places, whether it is improving in others. So today, we have a much more detailed understanding of the Mediterranean ecosystems than we had at the outset of these ecological studies. Because ecology, when all’s said and done, is in fact very recent. It wasn’t really taught when I started at university in the early 1960s.

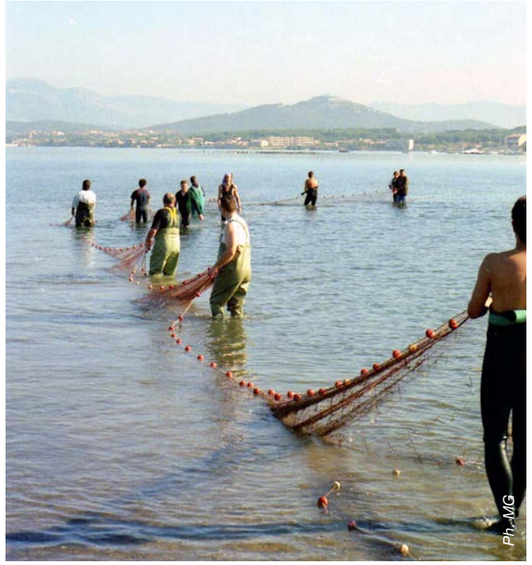
It’s clear that the MPAs are a means to improve the situation of ecosystems that are being severely degraded throughout the Mediterranean because of destructive human activities, such as building concrete constructions, for example, which is still being carried out in many places without taking into account at all sites where organisms reproduce. Most marine life develops within a very narrow coastal strip, on the continental shelf. And unfortunately this is also where most of the damage and pollution caused by our activities occurs. Today, restoration operations are being launched in certain coastal areas, which are the breeding grounds and real nurseries for most species.

➔ TO GO BACK TO THIS POINT REGARDING THE ISLAND OF LES EMBIEZ, AND IN PARTICULAR THE BRUSC LAGOON. CAN WE STILL TODAY CONSIDER IT AS A BIODIVERSITY HOTSPOT?

The Brusc lagoon, which I’ve known well for more than 60 years, has always been an environment that is rich in biodiversity. There was a traditional kind of fishing there, the *seinche**, which was not destructive of the ecosystem, despite what may have been said a few years ago. This practice was banned although it wasn’t responsible for the degradation of the lagoon, where there has been a gradual disappearance of the seagrass meadows, a breeding ground if ever there was one, the spawning ground for many species. Today, the *Institut océanographique Paul Ricard* has been working on the restoration of this lagoon ever since it became part of the European Natura 2000 network. The researchers are working on this project as part of the Sar-Lab programme [(2)], which involves restoring the environment, the seagrass meadows that existed previously, *Posidonia oceanica*, *Cymodocea nodosa*, *Zostera noltii*.

Glossary

Seinche (or inshore seine net)
A fishing technique used in shallow water, enabling large quantities of sea bream to be caught: salema, gilthead bream, white bream, and other species. It involves encircling shoals of fish by forming a wall of nets with meshes too fine for the fishes to get caught in them. The fish trapped in the net are gradually drawn towards the shore, and the youngest individuals are released.



Seinche fishing, also called inshore seine net fishing, shown here in the 1970s.

The former salt pans of the island of Les Embiez (SE France) border the Brusc lagoon. Classified as a Natura 2000 site, it is currently being restored under the Sar-Lab programme, run by the researchers from the Institute.

(2) To find out more: http://www.institut-paul-ricard.org

>>

>>

After a few years, we can see that this work is bearing fruit, we can see that thanks to our experimentation, these meadows that are vital for biodiversity are gradually beginning to reappear. It's a slow process, but it shows that we can restore an environment as long as we stop damaging it, that goes without saying. The development work in the surrounding area had caused serious pollution, which resulted in the degradation of the lagoon and caused the alteration of certain currents which today we have to restore. Climate change is no doubt also responsible for this alteration.

Unfortunately, in the vicinity, new harbour construction work is likely to cause further disturbance to the lagoon environment. It will have to be managed in a very intelligent way if we want marine life to be maintained.

> *“We can restore an environment, as long as we stop damaging it”*

➔ TODAY, DO YOU HAVE AN OPTIMISTIC VIEW OF THE MEDITERRANEAN?

I am an optimistic person at heart, but I am much more worried that I was only ten years ago. Worried about global climate change, let's not just talk of warming, but rather of climate disturbance.

And in the Mediterranean, a sea that is considered as extremely polluted, still today, we know how much effort has been deployed in the western basin by the countries of the European Community, today known as the European Union. Considerable progress has been made since the 1980s regarding sewage treatment, coastal renovation, and the protection of species and their habitats, with the creation of the Marine Protected Areas. Unfortunately, we continue to degrade the environment in the waters off certain very large Eastern Mediterranean cities. I take the example of Beirut, where we can see that thousands of tons of macro-waste has been stocked which is pushed out towards the sea to form embankments for construction. This is a complete aberration. Factories in Tunisia, for example, continue to discharge their pollution along the coast, and off Alexandria, drifting oil spills can be observed. So if we do not deal with these issues, we shall not succeed in maintaining marine life in the Mediterranean. And then again, it will have to become once more a place of peace and freedom. Biodiversity and guns don't make for a happy couple! ■

Interview with Isabelle Croizeau
January 2020

Ph. P. Lelong

Juveniles of damselfish, Chromis chromis.

Longstriped blenny, Parablennius rouxi.

Gorgonocephalidae, Astrospartus mediterraneus.

Sunset cup coral, Leptosammia pruvoti

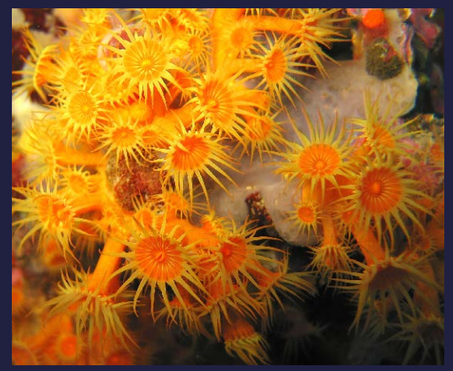
Peacock wrasse, Symphodus tinca

Some 12 000 species inhabit the waters of the Mediterranean, and represent about 10% of the biodiversity of the World Ocean

False coral, Myriapora truncata

Sea slug, Flabellina affinis

Red mullet, Mullus surmuletus.



Yellow cluster anemone, Parazoanthus axinellae

Ph. P. Lelong

THE
NEWSLETTER
N°18 - 2020/2021

2021 2030 United Nations Decade of Ocean Science for Sustainable Development

" With a greater understanding of the science, we must also reinforce our work on **Ocean literacy…"**

UNESCO Director-General,
Audrey Azoulay,
at the opening of the 51st Session
of the IOC(*) Executive Council.

(*) Intergovernmental Oceanography Commission

TO CREATE OR RECREATE REAL LINKS BETWEEN HUMANS AND THE OCEAN...

Ocean literacy, *a major priority*

The United Nations Decade of Ocean Science for Sustainable Development, announced in 2017 during the 72nd session of the United Nations General Assembly, began in February 2021. The Decade is a real recognition of the importance of the role played by the Ocean in climate regulation: by supporting the ocean sciences, the international community thus seeks to improve our chances of achieving the Sustainable Development Goals of Agenda 2030.

But to be more effective, sharing knowledge on the Ocean must imperatively be underpinned by what is referred to as *Ocean literacy*.

OCEAN LITERACY IS BASED ON SEVEN MAJOR PRINCIPLES:

1. The Earth has only one Ocean, even if it has multiple characteristics
2. The Ocean and ocean life determine the terrestrial characteristics
3. The Ocean plays a major role in climate change
4. The Ocean has made the Earth habitable
5. The Ocean shelters a wide diversity of life forms and ecosystems
6. The Ocean and humanity are inextricably connected
7. The Ocean remains largely unexplored

The aim is to make all of us, throughout the world, more enlightened citizens by enhancing our knowledge of the marine ecosystems, by helping us to be more aware of the importance of preserving them, in particular by means of educational programmes; and to create, or recreate, real links between humanity and the Ocean. The Intergovernmental Oceanographic Commission (IOC) of UNESCO proposes to share knowledge on the world oceans by means of an internet portal *(Ocean Literacy Portal)*: ***oceanliteracy.unesco.org***

INSTITUT PAUL RICARD OCÉANOGRAPHIQUE
www.institut-paul-ricard.org

Printed on 100 % recycled paper. IMPRIM'VERT®

Photo: AdobeStock/hakase420